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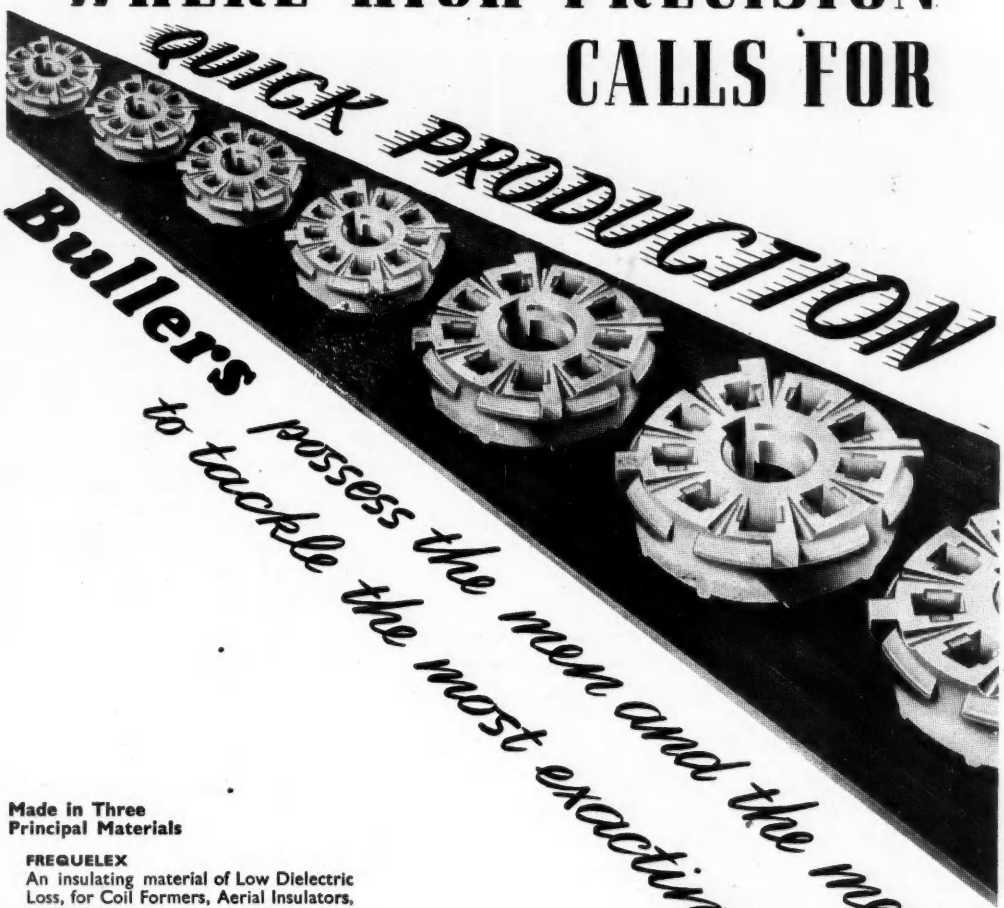

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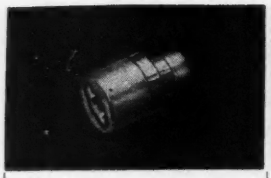

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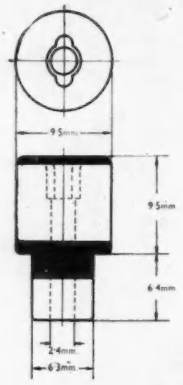

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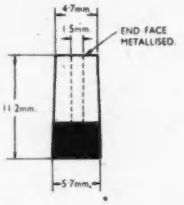

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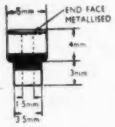

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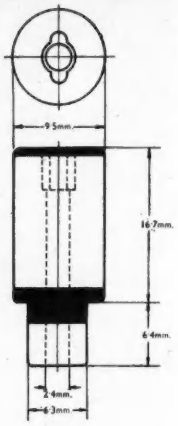

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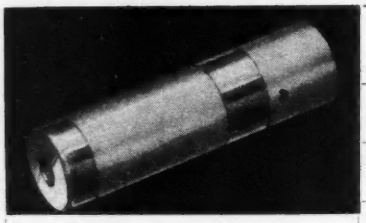

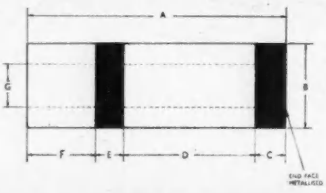

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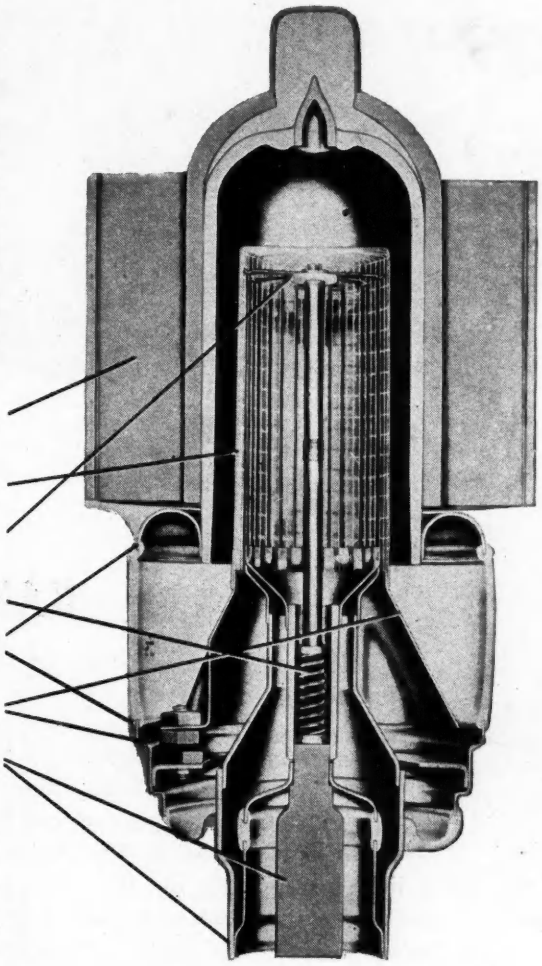

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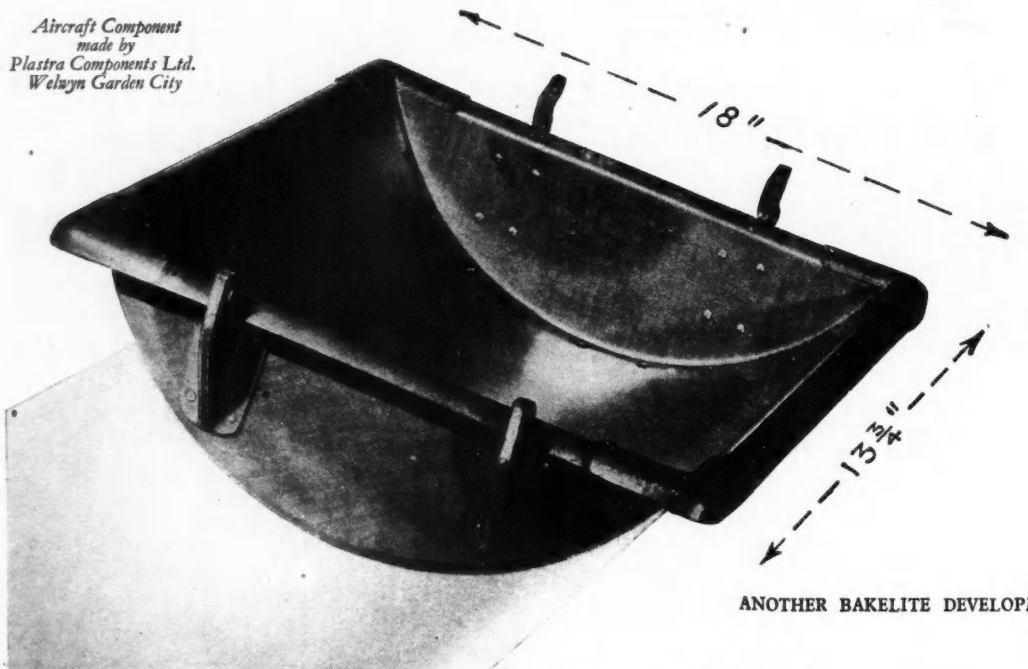

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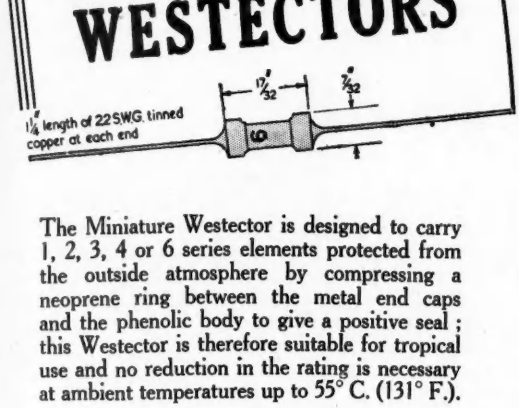

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APRIL, 1946

Volume XVIII. No. 218.

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Convention Comment

BY the time this appears in print the great Radiolocation Conference will have come and gone and many hundreds of workers in the greatest of all radio developments will have met and discussed their various contributions. Those who are not so fortunate as to have attended the meetings will have to be content with the reports and summaries that a miserably inadequate supply of paper allows to be printed.

In the note circulated by the Institution of Electrical Engineers to the Press there is the paragraph :

"Further, and of particular interest at this present time, when British Trade and prestige are of such importance abroad, it was realised that every possible assistance should be given to all sections of the Press to enable them to portray to the world the full facts of Britain's share of the work which created radiolocation and developed it into such a vital weapon in the recent war."

This memorandum could not have been read by the Government, to whom British Trade and prestige are of such importance, or they would have no doubt granted a few extra hundredweights of paper on which to publish news of such unique scientific value.

The Skiatron

Among the papers is one on the Skiatron, or Dark-Trace Tube, which was used for large-scale projection with considerable success. The proof of the written paper omits any reference to Dr. E. Rosenthal, of the Scophony Corporation, who described it as early as February, 1940, in an article in *Television & Short Wave World* (as this journal was formerly known). It is hoped that the final printed paper will give due credit to the originator.

Bats

Another contributor to the science of radiolocation is the humble bat (*Nyctalus noctula*, or its companions). Those who listened to Professor Hartridge's recent discourse at the Royal Institution* realised that the bat had developed its own radiolocation system independently of T.R.E. down to the last detail, and has in fact a highly specialised pulse technique suited to the obstructions in its path. Professor Hartridge also suggested that the bat has devised a method of I.F.F. or the equivalent, to enable it to identify its own pulse signal from that of its friends and relations. The only thing that cramps its style is a cold in the head, and then, like most sensible beings, it stays at home to recuperate.

* See also NATURE, Oct., 27, 1945.

Gold-Leaf

The gold-leaf electroscope, familiar friend of student days, has come into its own as a measurer of voltage at centimetric wavelengths. Who would have thought, when presenting the end of an ebonite rod to the cap of the gold-leaf electroscope (carefully insulated with sulphur, if memory serves), that the movement of the gold foil would be repeated years hence in modern laboratories surrounded by equipment whose existence was barely foreseen.

Television and Radar

Some time ago a discussion took place at the Television Society on whether television could profit from experience gained in radar technique, and the opinion was expressed that it was the other way about, at least, in the early days of radar.

Mr. Watton, in his paper on I.F. Amplifiers, bears this out by saying : "The I.F. amplifier used in radiolocation receivers has developed from the pre-war television receiver, but the conditions in a radiolocation equipment are so much more severe that there is now only a family likeness between them."

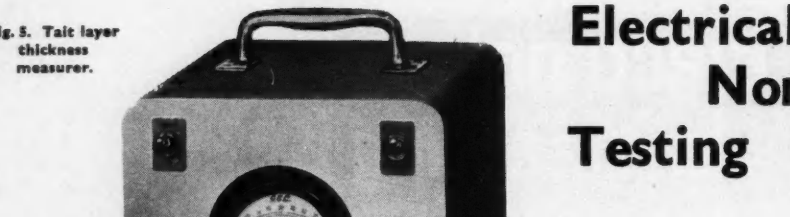


Fig. 5. Tait layer thickness measurer.

Electrical Non-Destructive Testing of Materials

By

G. R. POLGREEN, M.B.E., B.Sc., M.I.E.E., and G. M. TOMLIN, A.M.I.E.E.

A lecture given at the opening meeting of the Society of Instrument Technology, April, 1945

General

THE testing of materials is rightly considered to be one of the most important branches of industry and commerce, for it is the basis of all agreement on their value, quality and mode of application. In the past these properties of materials have been judged by a personal estimate based on experience or reputation, or else by a sampling test which frequently resulted in the destruction or loss of part of the material. To this disadvantage are often added errors due to lack of uniformity or to the unrepresentative nature of the sample, and it is thus evident that in a large majority of cases in modern industrial and engineering practice endeavours are continually being made to improve methods of testing.

The object of this paper is to review the comparatively new and important field of non-destructive testing of raw and semi-manufactured materials by methods involving electrical technology, with particular reference to the measurement of non-electrical properties by methods utilising electric currents and magnetic flux. Such methods have been in use to a limited extent for several years, but the subject had achieved such importance that just before the war a special series of meetings on non-destructive testing was arranged by the Joint Committee on Materials and their Testing and held under the auspices of the Institution of Electrical Engineers. (*See J.I.E.E.*, Vol. 84, May, 1939.) Several papers were presented by authorities from this country, the United States, Holland and Germany and a large part of the meetings dealt with electrical methods as compared with acoustic, optical and other methods, some of which have been in use for many years.

During the war years there has been a very marked increase in the applications of high-frequency technique, formerly associated solely with radio telephony, but more recently classified under the heading of electronics, and the widespread use of radar and other forms of electrical detectors has a special significance for peace-time industrial applications. There are already many applications of thermionic valve circuits to industrial uses which are giving satisfactory performances, although they are operating without the direct control and assistance of experts in electronics or electrical engineering, and it is important to realise that instruments of this type are far from the experimental laboratory stage in which many people have considered them to be.

The paper has been divided into two main parts, the first part dealing with the general nature of the subject with special reference to the correlation of the electrical and magnetic properties of materials with the physical properties which the instruments are required to measure, while the latter part deals with some typical electrical instruments designed during the past three years and now being used on a considerable scale. Two in particular, the magnetic sorting bridge and the crack detector, using respectively magnetic and electrical principles of non-destructive testing, illustrate the advantages of the latest electronic methods to the continuous or intermittent testing of materials.

Non-Destructive Testing

The chief advantage of non-destructive testing is that the material in question can be tested for some particular quality without impairing its adequacy for the service for which it is intended. If electrical technology is the basis of the test methods, several notable advantages over alternative methods become evident :—

(1) *Universality.*—All materials have definite and distinguishing electrical or magnetic properties so that electrical test methods can theoretically be applied to all materials.

(2) *Accuracy.*—Electrical methods of measurement are generally of greater accuracy and more easily standardised than other forms of measurement.

(3) *Simplicity.*—Modern electrical equipment can be made simple to operate so that unskilled testers can be employed. Much of the equipment for non-destructive testing can be made automatic or semi-automatic.

(4) *Flexibility.*—Use of electrical equipment for remote operation and indication or recording of test results.

In short, the electrical methods outlined introduce the practical achievement from both technical and economic standpoints of 100 per cent. testing for raw or semi-manufactured materials. If, for instance, all the components of an internal combustion engine can be tested before assembly by methods which ensure that they are all free from flaws of all kinds and are in the correct physical state of hardness, degree of temper, heat treatment and composition, it is certain that the reliability of the completed engine will be of a higher order than is possible with the use of the batch and sample testing methods which are in common employment at present.

It must be made clear, however, that these fundamental physical, chemical or metallurgical tests which are normally of the destructive category are not being superseded, but are being amplified by the electrical methods to be described. The basis of the whole of this non-destructive electrical testing is a correct correlation between the electrical properties of the materials and the corresponding physical properties and as this point is of such fundamental importance, this correlation is dealt with in some detail.

Electrical Properties of Materials

The electrical properties of materials can be conveniently summarised under three headings: electrical conductors, magnetic materials and electrical insulators (Table 1), and the chief points to note are :—

(a) *Conductors.*—The property of resistivity is fairly readily measured on some samples by means of the D.C. bridge or potentiometer, but in the case of large pieces of metal it is often difficult to obtain satisfactory electrical connexions without marking the surface of the metal. However, with A.C. of suitable frequency for the sample to be tested and the method used, it is possible to measure the resistivity of metals in terms ot eddy current losses or the screening effect, in which case there is no direct contact between circuit and sample. Thus the continuous testing of the properties of metal wires, sheet, foil, etc., can be arranged in this manner.

(b) *Magnetic Materials.*—The electrical properties of ferromagnetic materials are so marked that this is the group with the greatest possibilities in non-destructive testing, and this applies to almost all the various grades of steel. In the past, the testing of these properties has been a specialised process for the laboratory, but the development of cathode-ray oscillographs and circuits has resulted in the instantaneous measurement of B-H curves and hysteresis loops from which a very considerable amount of information can be obtained visually. By using suitable bridge circuits with combined direct and alternating currents, accurate measurements of incremental permeability can be quickly obtained and the other properties associated with the hysteresis loop, remanence, coercivity and saturation flux give a very detailed report of the physical and metallurgical properties of the material.

Group	Electro-Magnetic Property	Applications
(a) Conductors	Resistivity	Measured by D.C. (fixed sample) or A.C. (continuous testing) for structural uniformity or thickness of sheet, foil, etc.
	Para- or Dia-Magnetic	
(b) Magnetic Materials	Permeability	Structural uniformity. Air Gap length or layer thickness. Metallurgical Properties.
	Incremental Permeability	
	B-H Curve	
	Hysteresis Loop	Shape of loop denotes hardness, grain size, heat treatment, strain, composition, etc.
	Remanence	
	Coercivity	
	Saturation Flux	
	Magnetostriction	
	Resistivity	See (a)
(c) Insulators	Permittivity	Testing of purity and composition of non-metallic materials, liquids, chemicals, etc.
	Dielectric Loss	
	Resistivity	

Table 1. Electrical Properties of Materials used for Non-Destructive Testing

(c) *Insulators.*—The properties of dielectric materials, permittivity and power factor have been measured by electrical laboratory methods such as the Schering bridge with comparatively high voltages, but the resulting information has been largely used directly for the design and development of electrical equipment. With the development of high-frequency testing methods which can be made direct-reading and simple to operate, it is possible to obtain a considerable amount of information of the properties and behaviour of a large variety of solids and liquids which may be of no direct interest from the electrical standpoint, but which may be of importance in assessing the properties of chemicals, oils, fats or similar materials.

The insulation resistance of dielectric materials or the conductivity of magnetic materials are additional factors assisting in correlating electrical and physical properties. In addition, the photometric methods of measuring colour, gloss or similar properties, the non-linear characteristics of semi-conductors, temperature coefficient and thermo-electric effects, can all be utilised to assist in the non-destructive testing of materials.

Testing Requirements

The general requirements for non-destructive testing are the quick and simple measurement of the structural uniformity, purity or mechanical suitability of materials for the application under consideration or the measurement of dimensions which are inaccessible by ordinary methods. The first of these refers to the location of faults, cracks and other structural imperfections and a great deal has been accomplished with the use of X-rays, which will not only detect the faults but will also indicate their position and nature. This subject has been dealt with fully by Dr. Pullin in a recent paper before the I.E.E. and no further description of these methods will be given here, although the subject is strictly within the scope of the paper. It is, however, the opinion of the authors that such means, while admirable as laboratory and fundamental testing methods, suffer from the following disadvantages when used for routine inspection and testing :—

(a) Complication of equipment and operation.

(b) Comparative expense.

(c) Delay in obtaining results.

(d) Need for special precautions.

For the routine testing of structural uniformity of electrical conductors a method described later is the comparison of test samples with a standard which has been previously calibrated under laboratory conditions, the principle of operation being the use of high-frequency currents of the range 100 kc. to 10 Mc. Equipment of this type works on the assumption that the physical dimensions of the samples are reasonably uniform and this will generally apply to the routine testing of bar, rods, wire or sheet, possibly to die castings, but probably not in the case of other types of casting. Arrangements must also be made for the compensation of changes in temperature and composition. Several satisfactory methods of measuring

imperfections in magnetic materials are already in existence, and are based on the variation of reluctance of a magnetic circuit of which the sample forms a part. The faults can be detected by magnetic powder, compasses or search coils, and there is already a considerable literature on these subjects.

The variation of chemical composition or purity of materials is a comparatively unexplored part of the non-destructive testing field. Impurities will influence all the properties summarised in Table 1 and the actual method of test must be decided from the type of material and the nature of the impurities, once there is enough information accumulated under laboratory conditions for any specialised application to ensure that the results can be correctly interpreted.

The measurement of inaccessible dimensions is a very important part of this subject, and this applies not only to new materials, but to existing structures or equipment which have deteriorated due to ageing or corrosion. These conditions apply to boiler plates or metal pipes, the many types of protective layer used on sheet steel, and cable sheaths in which a simple and quick thickness measurement is required, and only the orthodox methods of destructive testing can be employed. Such tests can be made by measurement of resistivity, by the use of a magnetic circuit, of which the sample forms a part, or by supersonic impulses employing methods originally developed for echo sounding and anti-submarine detectors, but operating at considerably higher frequencies. The latter method is based on electronic technique using a quartz crystal to generate the high-frequency sound waves and a similar method can be used to detect imperfections in a large variety of materials.

An important group of tests for a large variety of materials such as foodstuffs, paper, timber or textiles is the effect of moisture. The simplest test is the measurement of resistivity by direct current, but for reasons already given, the best practical method is the use of the test material as the dielectric in a condenser, the properties of which can be measured by 50 cycle A.C. bridge methods.

Design of Electrical Instruments

Since this subject is being discussed from the instrument aspect, it is important to emphasise practical points in design which are often overlooked in equipment made up for laboratory use. Desirable properties for instruments to be used for industrial applications are :—

(a) Compactness, portability and robustness.

(b) Mains operation (if possible), with arrangements for compensating for normal mains voltage variations where these will affect the accuracy of the results.

(c) Simplicity of operation with all but essential controls and connexions sealed up inside the case.

(d) Speed of obtaining readings.

(e) Instructions for simple maintenance and replacement.

Indicating instruments, such as voltmeters or ammeters, used as detectors are usually more satisfactory than built-in galvanometers because it is often possible to use a valve-amplifier detector circuit which will give all the sensitivity required. If, as in the case of the detection of flaws in metal, no measurement has to be made, simpler detectors of the buzzer, bell, magic eye or light type can be used, and it is not difficult to arrange for the detector circuit to mark faulty samples or to operate a simple sorting mechanism in which faulty samples are segregated automatically.

Much criticism has been levelled at thermionic valve-operated equipment in the past because of the necessity to use special valves, often difficult to obtain, as replacements for industrial equipment which has to operate under very different conditions from, for instance, broadcast receivers. This matter has received considerable attention both from the valve maker and the circuit designer, and many modern circuits are less dependent on the actual characteristic of the valve than formerly. In general, it can be stated that modern industrial electrical instruments utilising thermionic valves will stand comparison with other sensitive instruments used for industrial applications and will give satisfactory service for long periods if handled with reasonable care and attention.

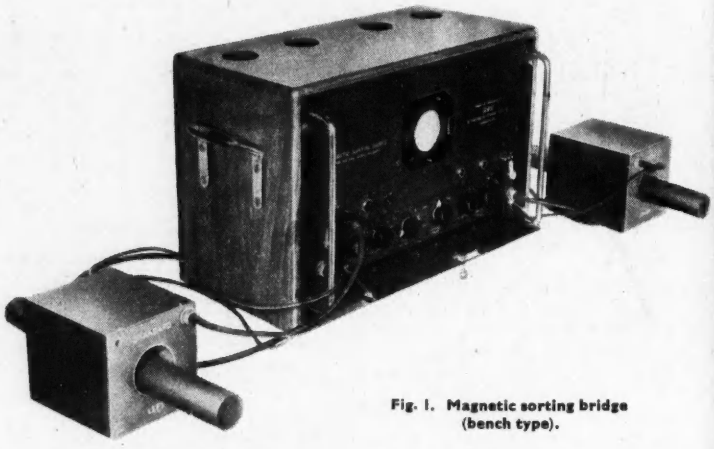


Fig. 1. Magnetic sorting bridge (bench type).

Under this heading comes equipment of the photo-cell type which offers considerable possibilities for non-destructive testing by the measurement or matching of colour, gloss or transparency. The use of quartz crystals which convert pressure to electrical impulses, and *vice versa*, opens up extensive possibilities of new instruments to measure pressure, weight or shock, and for the generation of supersonic sound waves which have considerable applications for measurement purposes. The variety of such industrial electrical equipment is such that there is only space for the description of two or three instruments here.

Magnetic Sorting Bridge

The magnetic sorting bridge (Fig. 1) was developed to meet an urgent requirement for 100 per cent. testing of ferromagnetic materials, particularly in the automotive industries where small deviations from specification in certain parts may have disastrous results. Such requirements are the testing of valve springs, valves, connecting rods, gudgeon pins, etc. During the war

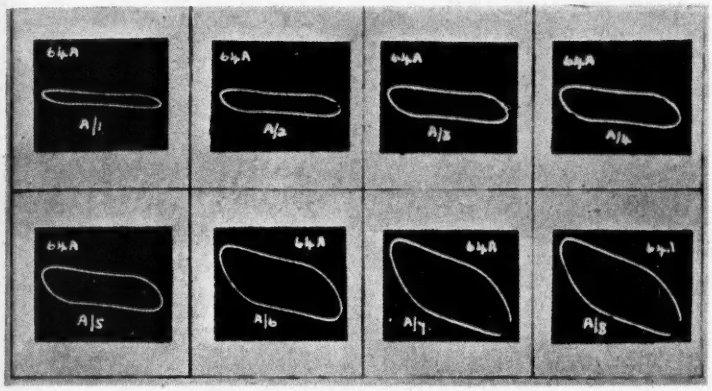


Fig. 3. Typical traces obtained from the magnetic sorting bridge.

years, with increased engine power outputs and high reciprocating speeds, the demand for such apparatus became acute, and the M.A.P. laid down a requirement for development work on a device which would enable 100 per cent. testing for chemical composition, hardness, tempering, etc. Thus the device had of necessity to be non-destructive, and the final result, known as the magnetic sorting bridge, has for some time fulfilled this function in all the major factories making internal combustion engines.

The problem was approached with the following requirements in mind:

(1) The answer given by the bridge must be easily interpretable so that relatively unskilled labour could be employed in testing.

(2) The testing time per sample must be short enough not to interfere with production.

(3) The sensitivity must be high enough to indicate very small departures from specification.

(4) Any of the normally possible variations must be instantly detected, *i.e.*, in one test. These variations are normally carbon content, nickel or molybdenum content, hardness and tempering.

In view of requirement (4) it was decided that the only reasonable method was to compare the unknown sample with a very carefully measured standard, and to provide qualitative as well as quantitative indication. This, of course, ruled out any meter indication, but would be satisfied by a picture on a cathode-ray tube whose shape and size bore some relation to the differences between the standard and the unknown. A visual image has also the advantage of being instantly interpreted, whereas meter indications usually require a certain amount of thought, particularly if more than one meter is used.

By using a bridge circuit with two inductances containing the standard and unknown samples, and feeding the bridge with mains frequency current, the samples are automatically taken through their hysteresis cycle, and if the field is large enough, saturated. Now the bridge is balanced for impedance, and since the current through each inductance is of the same frequency and phase, at any instant of time, with precisely similar samples, the bridge is balanced and the resultant voltage zero. This resultant voltage is the difference between the two dB/dt voltages across the inductances, where B is the flux density.

The bridge circuit (Fig. 2) consists of two accurately matched inductances, with two stable resistances. A 50-cycle voltage is applied from a screened and balanced transformer, and is variable from 10 to 100 volts. Fine balancing controls are provided and the bridge output taken through an attenuator to the grid of a high gain pentode valve. This valve supplied a voltage, amplified 350 times, to one grid of a pair of push pull valves. A portion of the A.C. voltage at the anode of this valve is applied to the grid of the second push pull valve, thus fulfilling the necessary phase conditions for push pull. The final amplified voltage between the anodes of the push pull pair is applied to the Y or vertical plates of the cathode-ray tube. In order to maintain a stationary trace, the X axis time base is taken from the same transformer which feeds the bridge, *i.e.*, a 50-cycle voltage. The net result will thus be that with the bridge in balance, *i.e.*, similar samples, there is no out of balance voltage, and no Y or vertical deflection, giving a single horizontal line and a deflection due to the 50-cycle "X" time base. The insertion of a sample not precisely similar to the standard in one of the inductances will give an out of balance voltage at some point of the hysteresis cycle. Now the shape and amplitude of the resultant trace on the cathode-ray tube will depend on the point of the cycle at which dissimilarity occurs, and upon the amount of dissimilarity. Due to the peculiar shape of the hysteresis loop, this out of balance voltage will, in general, not be sinusoidal, and it is the amplitude and order of the harmonics of the applied voltage which gives any sub-

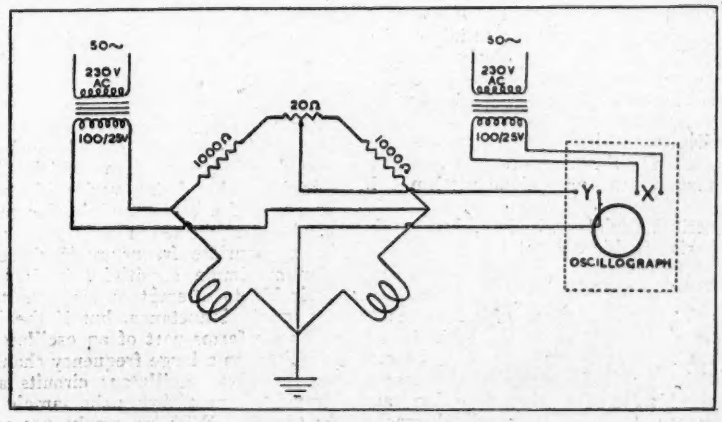


Fig. 2. Magnetic sorting bridge (simplified circuit).

stance or combination of substances their characteristic shape of traces.

The total valve amplification at the maximum settings of the attenuator and gain control is of the order of 22,000, and with the maximum voltage available applied to the bridge a rather extraordinary degree of sensitivity is attained. It is possible easily to measure cold heading strains in ordinary household pins, and carbon difference of the order of the second decimal point can be detected with ease. Similarly, a difference of 20 points on the Brinell Scale can be seen with a fairly low bridge voltage.

Some typical traces are illustrated in Fig. 3. The correlation between depth of case and amplitude in the "Y" direction can easily be seen.

A very interesting example of the use of a bridge of this nature is given in these figures. A 2½-in. diameter bar showed no difference when chemical analysis was made of drillings taken from various parts of the bar. However, on testing against a known standard in the sorting bridge, a peculiar shape of curve was obtained, which varied considerably from inch to inch of the length. Grave doubts of the efficacy of the sorting bridge were expressed by the manufacturer of the bar, but sulphur prints, taken from cross-sections which showed the maximum variation, disclosed extensive carbon segregations. It can be seen from the prints that the carbon content from centre to outside varies considerably, while the standard bar is uniform.

The uses to which this apparatus has been applied are manifold. It is in continuous use detecting internal flaws, which are big enough to break up the flux in the sample, detecting tiny pieces of ferro magnetic material in non-conducting material, sorting shells, etc. A particularly spectacular use was the discovery of 10 mild steel shells in a batch of 1,000, where non-discovery would have had disastrous results. Future possible uses are the measurement of paramagnetism or diamagnetism in chemicals, the sorting of non-magnetic materials like aluminium on the basis of eddy current loss, etc.

Crack Detector

The second piece of apparatus to be described in more detail is the radio frequency crack detector (Fig. 4). This device was developed specifically for the detection and measurement of longitudinal cracks

Fig. 4. General view of crack detector.

laps, or seams in uniform cross-section conductors. It will accommodate material from ⅛ in. diameter to 6 in. diameter, and in any length. The principle of operation is based on the well-known skin effect at high frequencies, which, briefly, means that current tends to flow more along the surface and ignore the centre of a conductor as the frequency is raised. The decay of current from the surface to the centre depends in a somewhat complicated manner on the frequency, and conductivity and permeability of the material.

Calculating the depth of current versus frequency for steel at room temperature, representative figures are in thousandths of an inch, 70 at 0.01 Mc/s., 28 at 0.1 Mc/s., 8 at 1.0 Mc/s., and 3 at 10 Mc/s. To make practical use of this phenomenon for the purposes of crack detection, the conductor is placed in the field of an inductance carrying high-frequency current, and eddy currents induced in it.

If the coupling between the sample and the inductance is fairly close, then the eddy currents affect the current flowing in the inductance. Now since the eddy currents are caused to flow around the surface of the sample, a longitudinal crack will affect the flow of current in the sample, and, if deep enough, will completely interrupt it. The effect on the inductance in which the sample is placed thus varies with the presence of a crack, and is also proportional to the depth of the crack if an appropriate frequency is chosen. For maximum sensitivity it is undesirable to attempt to measure the change in inductance, but if the inductance forms part of an oscillatory circuit, then a large frequency change occurs. Two oscillatory circuits are provided, one carrying the sample to be tested. With no cracks present, the frequencies are adjusted to give zero beat. The presence of a crack, however, alters one oscillator frequency and gives an audio beat whose frequency is proportional to the depth of the crack. This audio frequency is amplified and passed to a limiter circuit and frequency counting circuit. The meter in the diode may be calibrated in depth of crack for one particular type of conductor, and a neon lamp, which is operated by a D.C. amplifier valve, can be adjusted to operate at any point of the scale. The lamp is particularly useful when material is passing through the coil at high speed, for under these conditions a short crack would give no noticeable indication on a meter, but the lamp, which is without inertia, is infallible. A further use is for the rejection of cracks greater than a specified depth. It may often happen that a shallow crack is acceptable, but a crack at a depth of 5 thousandths of an inch or over not acceptable. By setting the lamp control knob to 5 thousandths the lamp lights when the instrument detects a crack at this or greater depths.

To make the equipment truly automatic, a spray painting device may be operated from a relay operated in conjunction with the lamp. Material may thus be passed through the device, and, without attention, be marked over each crack. Another possible variation is to use several spray painting devices operating at different depths of crack with different colours.

Thickness Meters

A compact instrument for the direct measurement of non-magnetic coatings on magnetic base is the Tait layer thickness meter (Figs. 5 and 6). The chief application is for the measurement of the thickness and uniformity of the many types of

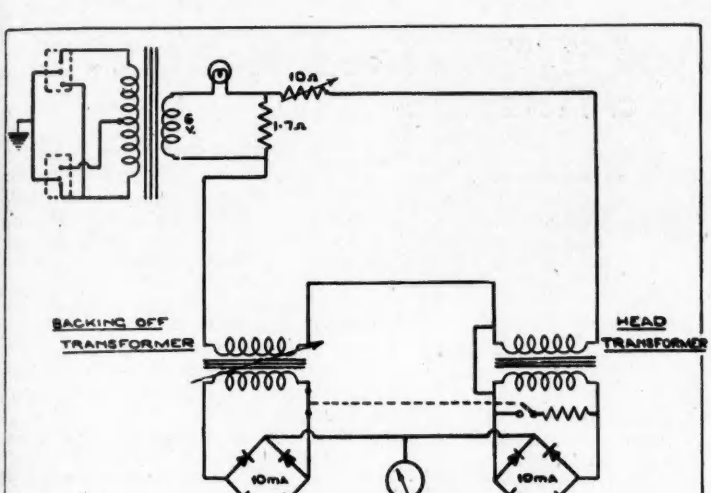


Fig. 6. Circuit diagram of Tait layer thickness meter.

protective coating used for sheet steel which are of two types:—

(a) Non-metallic, such as enamel, paint.

(b) Metallic, such as non-magnetic plating, sprayed metal or galvanising.

Current supplied from A.C. mains passes through a coil on one limb of an inverted-U magnetic core in an exploring head, the other limb of which is enclosed by a secondary winding which is connected to a rectifier instrument. If the exploring head is placed on sheet steel with a protective layer, the magnetic circuit of the core is closed by the base metal except for the two small non-magnetic gaps formed by the layer, and the current measured by the instrument will vary with the layer thickness.

For non-metallic coatings the instrument can be calibrated direct in thickness, and scale readings are from 1 to 20 or from 5 to 30 thousandths of an inch. For metallic coatings eddy currents are introduced in the layer which vary according to the conductivity of the metal and a calibration chart is supplied for each kind of metal coating used.

Compensation circuits are used to correct for the variation of magnetic properties of the base metal which may be considerable between different steel sheets, and errors will be introduced if the exploring head is used to measure coating thicknesses near the extreme edge of the sheet.

Another type of thickness meter is used for the continuous measurement of the thickness of metal foil coming from a rolling mill, since it is almost impossible under these conditions to use any micrometer relying on mechanical contact with the foil. This applies especially to aluminium foil which is made as thin as a fraction of a thousandth up to 25 thousandths of an inch and which must be controlled to great uniformity and maintained to nominal thickness values (Fig. 7).

The "exploring head" in this case consists of coils in two concentric cylinders connected rigidly by a U-member which enables the foil to be passed continuously between them, but without direct contact. High-frequency current is fed from a mains operated oscillator in the instrument case to one of the coils, and the other coil is connected through a rectifier circuit to the indicating instrument. This will either show deviations from normal thickness previously set by a calibration control or in certain conditions can be calibrated directly in thickness.

Conclusions

The paper has attempted to show that there already exist an appreciable number of electrical instruments for the non-destructive testing of materials, and indicates that there is a much wider field of application in many directions. Successful progress depends on close co-operation between electrical instrument designers and the many technical experts in the various industries associated with chemistry, metallurgy and engineering, since it is difficult for so wide a range of specialised knowledge to be concentrated in any one laboratory or development department. Many of the newer methods of applying electrical tests to industrial processes depend on correct interpretation of the results and the discrimination of the variables which occur during the operation of the testing process. By observing such precautions it will be found that the electrical non-destructive test methods will give valuable service in efficiency, accuracy, speed and simplicity of operation.

Acknowledgments are due to Salford Electrical Instruments, Ltd., an associated company of the General Electric Co., Ltd., for facilities granted to publish this paper.

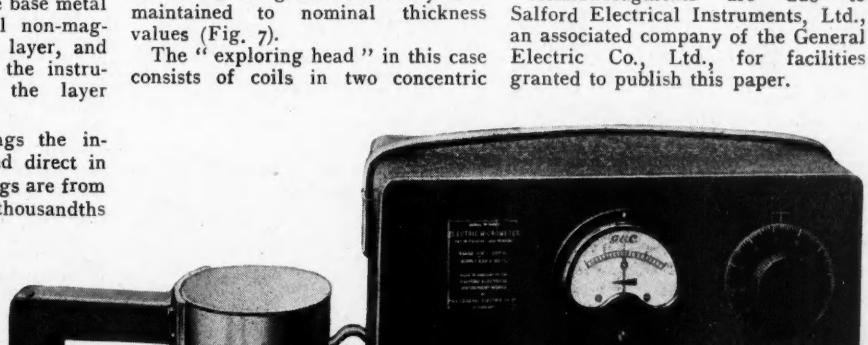


Fig. 7. Electric micrometer for continuous measurement of foil thickness.

The Design of a Screened Room

By C. C. EAGLESFIELD*

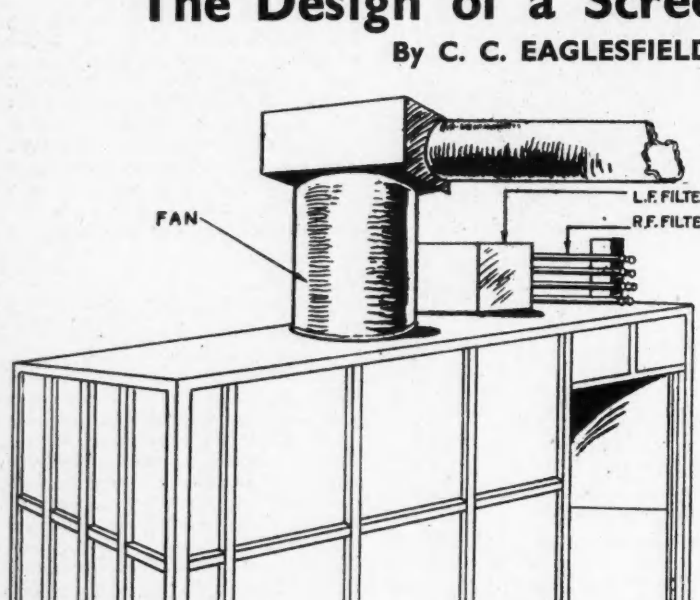


Fig. 1. General arrangement of the room constructed.

Introduction

IT is often found necessary to construct screened rooms either to confine a source of interference or to provide a place free from it. The latter is perhaps the most common. Screened rooms are expensive so some thought is justified before starting. Since it appears that little has been published on the subject the following notes are offered for the consideration of anyone who is about to build one. The matter is not suitable for exact calculation, but some general principles can be laid down, and a little arithmetic can be a useful guide.

The following is based on experience obtained by building a room to this specification :—

(a) The attenuation of outside interference should be 100 decibels at frequencies greater than 1 Mc/s.

(b) There should be sufficient space for all likely experiments.

(c) Four 2-wire low-frequency power supplies should be available, the maximum voltage and current rating of each being 500 volts and 10 amperes.

(d) Lighting and ventilation should be good.

(e) Entry and exit should be simple.

No upper limit was set to the frequency in the first condition : it had to be as high as possible, at any rate hundreds of Mc/s. The second condition was considered met by a room measuring 10 ft. × 8 ft. by 8 ft. high.

The third condition set requirements for the power lead filters.

Since there was no upper limit to the frequency, it was evident that the room would have to be a hollow metal shell, *i.e.*, that wire netting or perforated metal could not be used, except very sparingly for ventilation. There can be no penetration of field inside a completely enclosed space if the walls are of metal of adequate thickness. The thickness required to approximate to this depends on the metal and on the frequency, being less at higher frequencies. The room was therefore made of sheet metal. The thickness of the sheets had to be adequate for the lower frequency limit (1 Mc/s.). This point will be discussed later on.

Assuming for the moment that the required thickness of sheet will be reasonable (and, of course, that the various sheets are metallically bonded to make a continuous shell), there are two main paths by which interference is likely to enter the room : by the door and along the power leads. To prevent this the door must also be of sheet metal, and when shut be in metallic contact all round its four edges with the metal surface of the room. To do this with a door that is easily opened and shut is a mechanical problem that will be discussed in the next section.

To prevent interference entering along the power leads, suitable filters must be inserted. These can be conventional low pass filters. The attenuation of such a filter is easily calculated in terms of the impedances between which it is required to work. But these impedances may have almost any values in this problem, also the necessary attenuation is not known. Bold assumptions must

* Mullard Radio Valve Company.

therefore be made: it was assumed that the filters would be working out of and into resistances of about 100 ohms, and that their insertion loss should be the same as the overall attenuation required of the room, that is 100 decibels.

No low pass filter can be expected to attenuate at all frequencies above a critical frequency, since its elements are not pure reactances, and at frequencies greatly in excess of the critical frequency this may become very apparent. A simple solution is to put a number of filters in series, with different critical frequencies. This was the method used.

The filters for the lower frequencies require large inductances which are bulky because they must carry a high current; on the other hand, the condensers in the filters for the higher frequencies must be specially made so that their stray inductance is negligible. The design of suitable filters will be discussed in more detail later. Since the minimum amount of perforated metal is to be used, forced ventilation is necessary. The fan should be outside the room, and in addition to the place where the air enters it is advisable to have apertures (closed by perforated metal) for the air to escape. The room built had an aperture 2 ft. in diameter in the centre of the roof, through which air was forced by a fan in an air shaft from outside the building; there were two apertures 2 ft. sq. in the walls of the screened room near the floor. All three apertures were covered by perforated metal, details of which are shown in Fig. 2. It was, in fact, commercial perforated zinc. Since the fan is outside the room, there is no need to filter its power leads. One cause of regret is that the fan was not put at the far end of the air shaft, since the one used makes a lot of acoustic noise. It was

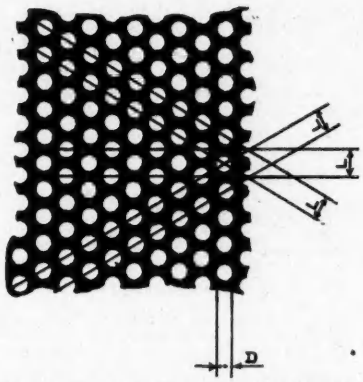


Fig. 2. The perforated metal used for the ventilators. Each hole has diameter D and is separated from adjacent holes by a distance L. D = 2.0 mm. L = 2.9 mm.

mounted on the roof of the screened room.

Since practically no daylight can enter when the door is shut, the room is always used by artificial light. It is therefore most important that the illumination be well arranged, to give sufficient light without glare or unnecessary heat. This is not very easy, but since it is a problem that occurs with any room, screened or otherwise, it will not be discussed further except for two remarks: the power for the lamps must go through the filters which are entirely adequate; fluorescent lamps cause interference at radio frequencies particularly when they are old.

Section 2 deals with the details of the construction, and Section 3 describes experiments to measure the attenuation.

The general conclusion is that the specification is met up to 550 Mc/s. and probably higher frequencies. Experience over about two years has revealed no defects and no case of interference penetrating the room has been recorded. That it is not an unpleasant place to work is best shown by the fact that for one reason or another experiments have often been made in it which did not require screening.

2. Practical Details of the Construction

Having sketched the general principles of the design, some of the points will now be considered in more detail.

First, the room is to have a metallic shell; what metal and how thick have been left undecided. Some hints on these questions can be got by applying the "skin effect" principle, which is that high-frequency currents flow mainly on the surface of a conductor. Thus if we imagine a high-frequency current flowing at some point on the outer surface of the metal shell, at the corresponding point on the inner surface a much smaller current will be flowing. The ratio of these two currents gives a very rough measure of the attenuation of an outside field produced by the shell.

By the usual formula the attenuation in decibels is thus proportional to

$$d\sqrt{\frac{\mu f}{\rho}} \qquad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where d is the thickness of the shell, μ the permeability and ρ the resistivity of the metal, and f the frequency.

The proportionality factor is such that copper 0.5 mm. thick gives 100 decibels attenuation at 2.3 Mc/s. Thus this thickness of copper would seem to be adequate for the specification (considering the roughness of the argument), and was used for the room constructed. However, since the ratio of permeability to resistivity determines the attenuation, iron would seem more suitable than copper. In the form of commercial tinplate, iron would be much easier

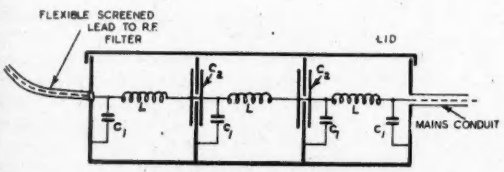


Fig. 3. The low-frequency filter. The box is divided into three compartments by partitions.
C_1 is a roll block condenser
C_2 is a "built-up" condenser
and L is a single layer solenoid
C_1 = 0.02 microfarad
C_2 = 0.00065 microfarad
L = 200 microhenries

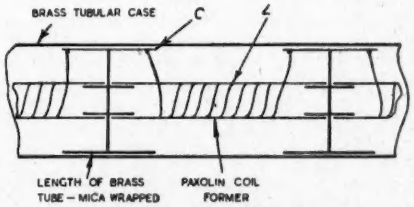


Fig. 4. A high-frequency filter.
The capacitance C, between the tube and the case, is about 0.0001 microfarad. L is a single layer solenoid. The number of turns is graduated along the filter, being 25 at one end and a direct connexion at the other end. Note that the inner assembly is completed first and then inserted bodily into the tubular case.

to solder than copper, due to its lower heat conductivity, and it is much cheaper.

The task of bonding the seams of the metal shell is a difficult one. There does not seem to be any practical alternative to soldering. The method used, which may not be the best, was to fix the copper sheets, with edges butting, inside a wooden frame; a strip of thin tinplate about ¾ in. wide was laid over each joint; the tinplate was then soldered to the copper along its edges. These seams were made inside the room. The floor was easy, the walls rather difficult, and the ceiling very difficult. For another room the writer would consider very seriously the substitution of tinplate for copper.

Now consider the ventilators: we can obtain a rough idea of their effect in terms of the electro-static screening of a mesh. This is a problem familiar in the calculation of the amplification factor of valves.

Imagine two small electrodes, one inside the shell and at a small distance x from it, and the other outside the shell and far removed. Near the inner electrode the shell is supposed flat, so that it can be replaced by an infinite plate. The material of the shell is not continuous, but is punctuated by holes of some sort. (In the valve problem we would probably have a grating of circular wires.)

There will be a certain capacitance between the two electrodes which would be greatly increased if the screen were removed. The ratio between the capacitances in the two cases is a measure of the effectiveness of the screen, that is of the attenuation provided by the screen. This ratio can be written as

$$x/a \qquad \ldots\ldots\ldots\ldots (2)$$

where a is a function of the geometry of the screen; it has dimension length and will be referred to as the aperture of the screen. Expressions are known for the aperture of certain simple forms of screen, and an estimate can be made for more complicated forms.

This argument gives us an estimate of the attenuation at a point distant x from the ventilator, and is probably reliable at low frequencies, that is when the dimensions (and particularly x) are small compared to the wavelength. The user of the room can avoid the immediate neighbourhood of a ventilator: a distance x = 50 cm., say, would seem reasonable from that point of view. But at 500 Mc/s. for instance (λ=60 cm.),

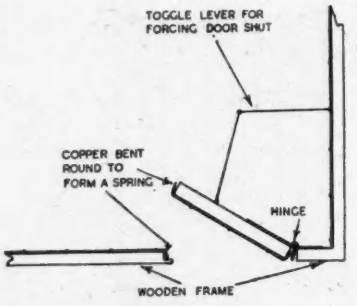


Fig. 5. Arrangement of the door to ensure metallic contact at the edges. Similar springs are formed at the top and bottom edges of the door.

it is evident that x = 50 cm. is not admissible and it would seem sensible to assume a much smaller value for x, which would give a lower estimate for the attenuation at that frequency.

If the screen consists of a grating of wires of diameter d evenly spaced at pitch p, the usual formula for the aperture is:—

$$\frac{p}{2\pi} \ln \coth \frac{\pi d}{p} \qquad \ldots\ldots\ldots (3)$$

A square mesh of wires spaced at pitch p in either direction has the same aperture as a grating whose pitch is $0.6p$.* The perforated metal shown in Fig. 2 is more complicated, but it is not so very unlike a square mesh of circular wires. A very rough estimate of its aperture is 0.0003 cm. Thus the attenuation at 50 cm. distance is 50/0.0003, that is 105 decibels. Thus this form of perforated metal may be considered to

* Eaglesfield: "Triodes with Square Mesh Grids," *Wireless Engineer*, October, 1942.

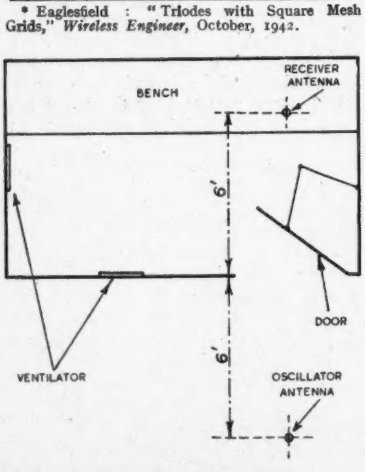


Fig. 7. Arrangement of the experiment for estimating the attenuation of the door.

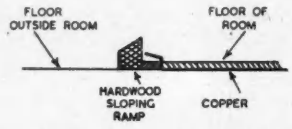


Fig. 6. Detail of ramp for protecting the lower door spring from being trodden on.

fulfil the specification at low frequencies and was used in the room constructed. It can be expected to start failing at frequencies of the order of hundreds of megacycles per second.

The next point that will be considered is the filters. The design of the low-frequency filter is straightforward. The one made is shown diagrammatically in Fig. 3. In addition to roll block condensers, condensers are "built up" on the partitions. These are plates insulated from the partition by mica. The stray inductance of these condensers is very small. The sketch only shows one filter: actually the box contained eight separate filters. The eight coils in each compartment were not screened from each other. Since each coil was required to carry 10 amperes the overall size was fairly big, the box being 4 ft. long, 2 ft. wide, and 1 ft. deep.

From the low-frequency filter connexion is made by eight flexible screened cables to eight identical high-frequency filters. These are tubular in shape as shown in Fig. 4. A number of short lengths of brass tube wrapped in mica are spaced inside a brass tubular case. The capacitances between these and the case are the filter capacitances. Each inner part is actually in the form of two tubes bridged by a disk: the innermost tube is merely a support for the paxolin coil former. The inductances of the coils are graduated from one end of the filter to the other. Commercial brass telescopic tubing was used. The filters were fairly long, each having 12 coils; the length of the casing was 4½ ft., and the diameter 1½ in.

From the high-frequency filters connexion was made to the screened room by flexible concentric cable. Once inside the room the wiring was mainly in conduits as a matter of routine, but no attention was paid to keeping it screened.

For convenience the flexible cables were terminated by concentric plugs and sockets. The crossover frequency at which the low-frequency filter is assumed to become unreli-

(*Continued on page 112.*)

Microphones

A Detailed Review of their Design and Characteristics

By S. W. AMOS, B.Sc.,* and F. C. BROOKER, A.M.I.E.E.*

IT is the purpose of this series of articles to give an account of the fundamental principles of operation, the construction and the peculiarities of microphones of various types with particular attention to the part that modern electro-acoustics has played in their design.

There are three types of alternating quantity concerned in this series, namely, the oscillations which occur in air (acoustical vibrations), those which occur in solid objects (mechanical vibrations) and oscillations of electrons (alternating currents or voltages). A microphone involves all three types since it has first to convert acoustical into mechanical energy and then to transform mechanical into electrical energy. The method of securing the first conversion—acoustical into mechanical energy—is almost invariably achieved by the same means, no matter what the type of microphone, and this is by the provision of a diaphragm, the size of which is one of the factors determining the degree of coupling between the acoustical and mechanical systems.

Although a certain amount of variation occurs in the shape, size and mass of diaphragms (which play an important part in determining the frequency characteristic), it is chiefly in the means of obtaining the mechanical-electrical energy conversion that differences occur between the various types of microphone and this has been chosen as a convenient means of classifying the various types of microphone. We can distinguish the following different methods of achieving this conversion—by means of a varying resistance (carbon-granule type); electro-magnetic induction (ribbon and moving-coil types); electrostatic action (condenser type); and piezo-electric action (Rochelle salt crystal type).

Electro-Mechanical Analogies

The analogy between a mechanical vibrating system and an A.C. circuit can be seen from Fig. 1 (a) and (b).

Fig. 1 (a) represents a mass, m, capable of sliding between guides which provides frictional resistance to any movement. We shall assume that the frictional force, r, provided by the walls of the guides is directly proportional to the velocity of movement of m, and is equal to r dynes per cm/sec. The spring, S, provides the elastic restoring force, *i.e.*, "stiffness," and we shall assume that the magnitude of this restoring force is directly proportional to the displacement, x, of the body and is numerically equal to S dynes per cm.

If m is acted upon by a force f_M which varies sinusoidally with time, then we may say:

$$f = F\sin\omega t$$

in which F is the amplitude of the force. We thus have the following differential equation for the motion of the body, m:

$$f_M = m.\frac{d^2x}{dt^2} + r.\frac{dx}{dt} + S.x = F\sin\omega t$$

which may be rewritten:

$$f_M = m.\frac{dv}{dt} + r.v + S\int v.dt = F\sin\omega t \quad \ldots\ldots (1)$$

This compares directly with the differential equation for the electrical case in Fig. 1(b) where:

$$e = L\frac{di}{dt} + Ri + \frac{1}{C}\int i.dt = E\sin\omega t \quad \ldots\ldots (2)$$

The steady-state solutions of (1) and (2) are identical in form. They are:

$$v = \frac{f}{r + j\left(\omega m - \frac{S}{\omega}\right)}$$

for the dynamical case

and:

$$i = \frac{e}{R + j\left(\omega L - \frac{1}{\omega C}\right)}$$

for the electrical case

the quantities in special type (v,f,e,i) being R.M.S. values.

Just as electrical impedance is given by $\frac{e}{i}$ so mechanical impedance is given by $\frac{f}{v}$, *i.e.*, $\frac{\text{Force}}{\text{Velocity}}$. Comparing the differential equations (1) and (2) we see that displacement ($x = \int v.dt$) in the dynamic system can be compared with quantity of electricity ($q = \int i.dt$) for the electrical case, and their rate of change with respect to time are likewise comparable, *i.e.*, velocity and current are analogous as suggested in the solutions of the differential equations. The dynamic system can be compared with an electrical circuit possessing inductance, capacitance and resistance in which the inductance is represented by the mass of the body, the capacitance is given by the reciprocal of the stiffness (known as "compliance") and the two resistances are analogous. Resonance in the dynamical case occurs when:

$$m\omega = \frac{S}{\omega}$$

giving $$f_R = \frac{1}{2\pi}\sqrt{\frac{S}{m}}$$

This equation is important as it represents the behaviour of a diaphragm for a constant applied force. If the stiffness and the mass of a diaphragm are such as to give resonance at a frequency within the audible range, then excessive amplitude may be developed at that frequency and frequency distortion will result. Suppose, however, that the stiffness is very small so that compliance is large and gives resonance at a very low frequency, below the audible range. For frequencies within the audible range we have (if the resistance is small):

$$= \frac{f}{r + j\left(\omega.m - \frac{S}{\omega}\right)} \approx \frac{f}{j\omega m}$$

i.e., the velocity of movement of the diaphragm is inversely proportional

* Engineering Training Dept., B.B.C.

to frequency for a constant applied force. A diaphragm which behaves in this way is said to be *mass controlled*.

Similarly, it can be shown that for "*elastic*" (or "*stiffness*") control where the compliance is very small, the velocity is directly proportional to frequency; and that when resistance predominates, the velocity is independent of frequency, again for a constant applied force.

Acoustical Vibrating Systems

Fig. 2 represents a model not unlike the dynamical model of Fig. 1, but which is intended to introduce the idea of acoustic elements. It is a Helmholtz resonator, consisting of a closed box of volume V connected to the open air by means of a tube length l and cross-sectional area S. If we consider the elasticity of the volume of air V as replacing the spring in the dynamical model, the mass of air in the narrow tube as equivalent to the solid mass, and the sound wave which causes motion of the air along the tube as a sort of piston acted on by a sinusoidal force, then we should have no difficulty in following the analogy, even though the exact mathematical analysis is beyond the scope of this article.

Consider the forces acting upon the mass of air within the tube when it has been slightly displaced from its equilibrium position by the action of a sound wave impinging on the open end.* It will be found that the differential equation of motion of the mass of air in the tube is of the same type as those we have already discussed for the mechanical and electrical systems. Instead of expressing the motion in terms of the linear displacement, x, of the air particles in

Standard Telephones & Cables moving coil microphone.

* In Fig. 2 the wavelength has deliberately been shown very small in order to get it into the picture: in actual fact it should be large compared with the dimensions of the cavity and the tube in order that the simplifications mentioned in the text shall apply.

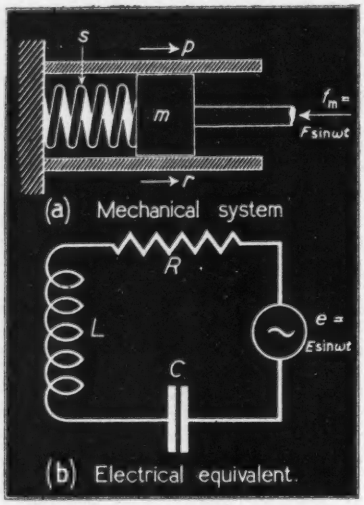
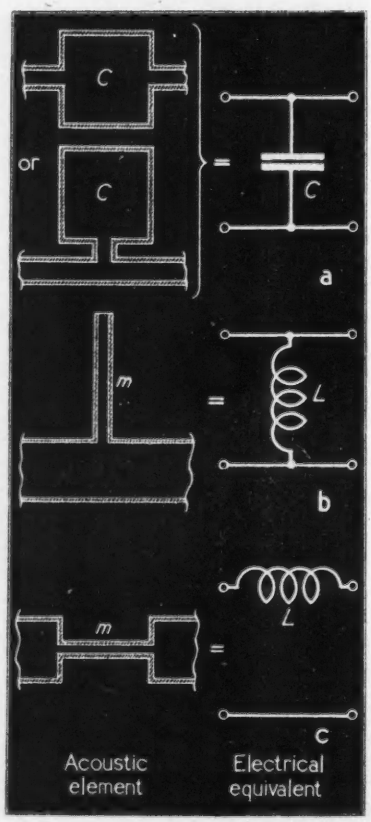


Fig. 1 (above). Mechanical and electrical tuned circuits.

Fig. 3 (below). Acoustical and electrical equivalents.



Rothermel-Brush crystal microphone with pre-amplifier.

the opening, it is more convenient to use X, the volume displacement, as the variable. This is the linear displacement, x, multiplied by the cross-sectional area, S, of the opening. This enables us to state the differential equation as follows:

$$p = A.\frac{d^2X}{dt^2} + B.\frac{dX}{dt} + DX = P_o\sin\omega t \quad (3)$$

in which p = instantaneous pressure and P_o = pressure amplitude

A is a constant (known as "inertance") involving the mass of air in the opening; B is a factor which involves the frequency and is analogous to resistance; and D corresponds to capacitance and is a function of the air volume in the enclosed space. The solution to this equation is:

$$X = \frac{p}{B + j\left(A\omega - \frac{D}{\omega}\right)}$$

Comparison with the previous solutions suggests that this acoustical system may be compared with an electrical circuit containing inductance and capacitance in which the mass of air in the tube is a function of inductance and the closed volume is a function of capacitance.*

The resonant frequency is given by:

$$f_R = \frac{1}{2\pi}\sqrt{\frac{D}{A}}$$

which may be shown equal to:

$$\frac{c}{2\pi}\sqrt{\frac{S}{Vl}}$$

where c = velocity of sound in air
S = cross-sectional area of tube
l = length of tube
V = volume of contained space

* This statement requires some qualification. It must be realised that the mass of air in the tube will also have elasticity, and the volume of air will have mass. However, provided that the dimensions are small compared with the wavelength involved, it is safe to regard air in a tube as an inductance, and a small cavity as a condenser.

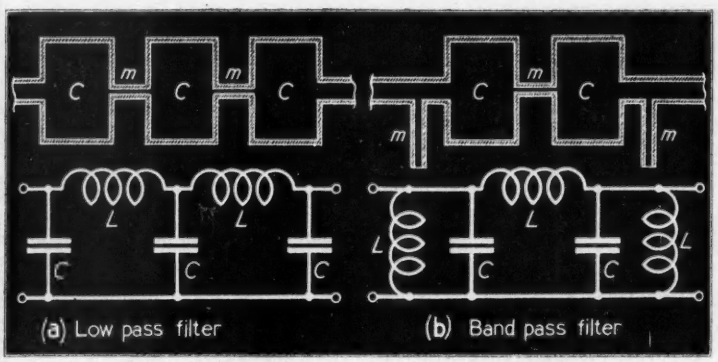


Fig. 4. Acoustical networks and their electrical equivalents.

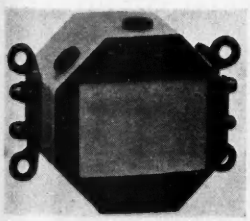
The acoustic impedance of a circuit is given by $\frac{\text{Pressure}}{\text{Volume velocity}}$ which may be written as $\frac{\text{Force}}{\text{Area}^2 \times \text{linear velocity}}$; whereas mechanical impedance, as shown earlier, is given by[1] $\frac{\text{Force}}{\text{Linear velocity}}$. Hence acoustic impedance

$$= \frac{\text{Mechanical impedance}}{\text{Area}^2}$$

Equations (1), (2) and (3), and their three corresponding solutions, show very convincingly the very close degree of correlation that exists between electrical, mechanical, and acoustical systems.

Electro-Acoustic Analogies

Before concluding this section it will be convenient to consider how these acoustic elements (*i.e.*, masses of air contained in slits, cavities, or pipes) may be utilised in the design of microphones. For, in the same way that judicious use of resistance and reactance in the electrical circuit allows practically any desired frequency characteristic to be obtained, so may acoustic elements be proportioned to give this same ideal. We have already seen that conditions of resonance may be achieved in such things as tubes or cavities if the dimensions are comparable with the wavelengths involved. (This, of course, is the principle of the organ pipe.) In most cases of microphone design resonances are undesirable, but there is at least one case where the design has been specially modified to attain resonance at a particular frequency in order to make good an otherwise large drop in level, and this will be discussed later.



Marconi carbon granule microphone (Reisz type).

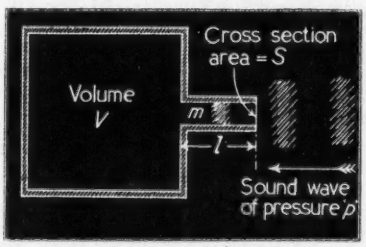
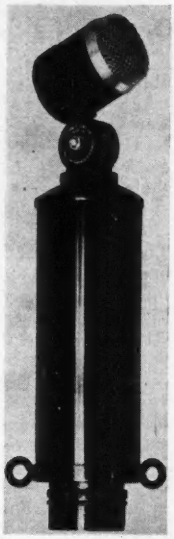


Fig. 2. Acoustic model (Holmholtz resonator).

If a tube is made very narrow compared with its length (the same applies to a narrow slit) it still behaves as an electrical circuit possessing inductance, capacitance, and resistance, but in this case the resistance is appreciable and the Q is low. In fact, it is possible—by suitable proportioning of the dimensions—to vary the ratio of reactance to resistance over a wide range. Since cavities are predominantly capacitative, it follows that almost any type of acoustical filter—high pass, low pass, or band-pass—may be produced by suitable arrangement of cavities, tubes, or slits.

When we come to the design of moving-coil microphones, it will be seen how the art of applied acoustics in this way has been carried to a very high degree. Meanwhile, it is as well to know the general rules for drawing the equivalent electrical circuit when faced with an acoustical or mechanical "network." The chief difficulty is that of distinguishing between shunt and series elements. It is obvious that if the acoustical element forms a side path or leakage from the main flow of air, then the equivalent electrical element is placed in *shunt*. Thus a cavity in a pipe (*see* Fig. 3(a)) may be regarded as equivalent to a shunt condenser, and an open pipe joined on to the main one (Fig. 3(b)) acts as a shunt inductance, always provided, of course, that the dimensions of these acoustical elements are small compared with the wavelength involved. Where the equivalent electrical circuit is not obvious the idea of considering extreme cases is useful. As an example, consider the acoustic circuit shown in Fig. 3(c), in which there is a reduction in the diameter of the main pipe for a certain length. This constriction represents an inductance, of course, but is it shunt or series? Consider the extreme case when the constriction is so small that the pipe is practically closed. The flow of air is clearly practically cut off by doing this. The inductance of such a tube approaches infinity as the diameter approaches zero, since the acoustical inductance is given by $\frac{\text{Mass of air}}{(\text{Cross sectional area})^2}$. If, in an electrical circuit, an infinite inductance stops the current flow, obviously the inductance must be a series one. Examples of a low-pass and a band-pass acoustical filter are given in Fig. 4 (a) and (b) together with their electrical equivalents.



Marconi condenser microphone with pre-amplifier.

(To be continued.)

Design of a Screened Room

(*Continued from page* 108.)

able and the high-frequency filter to take over is about 50 Mc/s. Attempts were made to measure the insertion loss of the high-frequency filter at 45 Mc/s. upwards. It was greater than could readily be measured.

The method of obtaining an electrically tight door is shown in Fig. 5. The copper of walls and door is bent round to form springs on all four edges of the door about 2 inches long. These springs engage each other when the door is shut and the door is locked home by pushing on the lever shown in the figure. A device (not shown in the figure) breaks this lever from outside the room in case of accident. The lower spring is protected from being trodden on by the hardwood sloping ramp shown in Fig. 6. The springs are kept polished and well covered with vaseline.

The general construction of the room is shown in Fig. 1. It was built inside a larger room. A wooden frame was made first, lined inside with boarding, and the copper inside that. The copper floor was covered with linoleum and the copper walls painted white. The roof was a convenient place to put the filters.

Attenuation Measurements

In this section the results are given of attempts to measure the attenuation by the room of outside interference. The word " measure " is used, but it is well to emphasise that " estimate " would be a better word, since the experimental difficulties were so great that accurate measurement was out of the question.

One wants to know the ratio of the field inside the room to the field at the same spot were the screening removed. To obtain this ratio one might measure the field inside the room, the source of the interference being remote; and then assume that the effect of taking the receiver outside the room is the same as removing the screening. This would not be an impossible experiment, but clearly there would be many practical difficulties at the higher frequencies.

A simpler experiment was therefore devised. This was to measure the attenuation introduced by shutting the door. The room will clearly have some attenuation even with the door open, which can be expected to be considerable at low frequencies, but much less at high frequencies. Thus the total attenuation must be greater than the attenuation due to shutting the door. The door experiment will therefore give a conservative estimate of the attenuation of the room. The arrangement is shown in Fig. 7, an oscillator being set up outside the room and a receiver inside, each with an antenna appropriate to the frequency. The field of the oscillator was measured first with the door open, then with it shut. The receiver was calibrated by a signal generator. This was done at three frequencies: 45, 200 and 550 Mc/s.

At 45 Mc/s. the attenuation due to shutting the door was of the order of 90 decibels. It was not possible to say by which path the residual field entered the room.

At 200 Mc/s. the attenuation was again of the order of 90 decibels. It seemed that the residual field entered by the door and through the nearest ventilator, the two paths making about equal contributions.

At 550 Mc/s. the attenuation was of the order of 70-80 decibels. The residual field appeared to be entering through the ventilator. At this frequency and to a lesser extent at 200 Mc/s., measurements were complicated by standing waves in the room, and were particularly affected by movements of the experimenter: he had to be careful to stand always in the same place. It was observed that if the door springs were deliberately raised so that a few inches were not in contact, the residual field was greatly increased. This last observation is an important one as it shows that the trouble taken to get a continuous shell was necessary at the higher frequencies.

The door experiment was not convenient at frequencies much less than 45 Mc/s. The only observation made at lower frequencies was as follows. At frequencies about 1 Mc/s. it was found that broadcast transmitters could not be heard even with the door open unless the aerial wire projected outside the room. A few inches of wire beyond the open doorway brought in a loud clear signal, which disappeared when the wire was withdrawn into the room. This showed that the attenuation of the room with the door open was very considerable at low frequencies. No leakage was observed through the filters at any of the frequencies tried: the receivers all took their power from the mains, as did the oscillators in the door experiment.

To sum up the results of these tests: it seems probable that the specified attenuation, 100 decibels, is realised between 1 and 550 Mc/s.; and almost certainly there is considerable attenuation at frequencies well outside this band.

It is interesting to consider what must be done to obtain the same attenuation at much higher frequencies. The tests at 550 Mc/s. showed that the ventilators were beginning to fail and there were indications that the door would fail at much higher frequencies. The ventilators could be made double with a separation between the two layers of perforated metal. The filters are no problem, as an additional filter could be made, on much the same principles as the one described. The door is the difficulty: it seems likely that two doors would be necessary, say, one opening inwards and one outwards.

A Note on the Protection of Heaters for Cathodes

Heaters for the cathodes of valves or C.R. tubes are usually made of tungsten wire or some similar material, insulated by a coating, say, of alumina or beryllia. This coating is sintered by high-temperature treatment, which renders it hard but somewhat brittle, and hence liable to get scraped or broken off during insertion in the cathode, especially if the shape of the heater is at all complicated. Any damage of this nature is, of course, likely to give rise at a later stage to faulty insulation between heater and cathode.

It is therefore desirable to protect the insulation on the heater until the latter is safely in position within the cathode; and this may be done very satisfactorily by coating the insulated heaters with a skin which can be removed later. A solution of nitrocellulose in amyl acetate, applied by dipping or spraying, is one example of a suitable material for the purpose.

The acetate evaporates, leaving a tough skin, which, however, readily vaporises during the heat processing of the tube, and the vaporised nitrocellulose is then removed during the exhausting stage. Other materials are also suitable—for example, celluloid may be substituted for the nitro-cellulose, and butyl for the amyl acetate.

—*Communication from E.M.I. Laboratories.*

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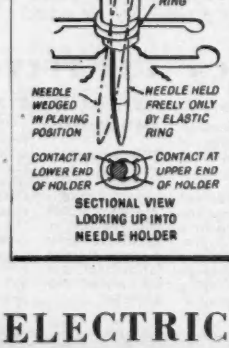
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Complex Waveforms

Commencing Part IV of the Series to Illustrate Cathode-Ray Tube Technique

By HILARY MOSS, Ph.D., A.M.I.E.E.

The Harmonic Synthesiser

Introduction

SOME knowledge of the theory of complex waveforms is essential to every radio engineer. Few, if any, triumphs of human thought since Newton's laws and the discovery of the calculus can have had so far-reaching an influence on almost all the physical sciences as Fourier's famous theorem. In radio engineering, which is largely the study of complex wave-shapes in complex networks, the significance of Fourier's conception is especially great.

Most engineering mathematical texts of degree standard contain a chapter entitled "Harmonic Analysis," in which Fourier's theorem is briefly treated, and then applied to the analysis of typical waves using the method of ordinates. This approach has the advantage of complete generality, and leads to the best method of dealing with waves containing a very large number of components of arbitrary phase. In many cases, however, the complex wave consists principally of only two or three components, and in such cases the generalised method is cumbersome. A better approach in such cases is via the theory of symmetry, the method of envelopes, and superposition. These are the methods which will now be treated.* Even if they are not adequate techniques to employ in the analysis of waves containing large numbers of components, yet their initial application often shortens the full working. This account is therefore a useful complement to the study of the more general analytical method. It will be noted that the approach to the problem is synthetic rather than analytic—this has the advantage to the engineer of keeping the physical basis of the proceedings clearly in view.

Fourier's Theorem and its Special Significance in Radio

Principle of Superposition in Linear Circuits.

Stated physically, Fourier's theorem asserts that any periodic waveform satisfying certain conditions in regard to continuity (which are always met in practical cases) can be regarded as the sum of a number of purely sinusoidal waves (termed components) having frequencies which are integral multiples of the frequency of the resultant complex wave.

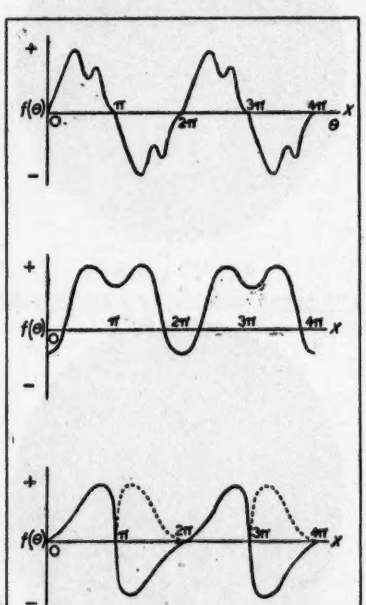


Fig. 1. *a* **(Above) alternance;** *b* **(centre) normal symmetry;** *c* **(below) skew symmetry.**

A more exact mathematical statement is as follows:

If any function θ denoted by $f(\theta)$ is arbitrarily defined within the interval $0 < \theta < 2\pi$, and has a finite number of points of ordinary discontinuity and a finite number of maxima and minima within the same interval, then provided that for all values of θ where $-\infty < \theta < +\infty$, $f(\theta + 2\pi) = f(\theta)$, *i.e.*, the function is cyclic, then $f(\theta)$ may be expressed by

$$f(\theta) = \tfrac{1}{2}a_0 + \sum_{k=1}^{k=\infty} (a_k \cos k\theta + b_k \sin k\theta) \quad \ldots\ldots\ldots\ldots (45)$$

The special importance of this conception to the radio engineer is a consequence of the principle of superposition in linear circuits. This principle leads directly to the result that:

In any linear circuit the resultant current which flows under the influence of any impressed voltage wave-shape is equal to the sum of the currents which would flow under the action of each sinusoidal component of the impressed voltage wave considered separately.

This fundamental theorem applied in conjunction with Fourier's conception permits an immense step forward in linear circuit analysis, since the response of any linear network to any impressed cyclic voltage wave is defined in terms of the response of that network to simple sine waves. The impressed wave is broken up into its components; the current due to each component is then determined (by elementary methods such as j notation, etc.) and the currents are summed. An interesting example of this type of computation has been given by Scroggie.[1]

Although the working is usually very tedious, the method is important on account of its complete generality, and because of the insight it gives into the mechanism involved.

The first step in such computations is the determination of the component waves in the complex waveform.

Definitions

Cyclic (Periodic) Wave.

A cyclic wave is one which repeats itself indefinitely. Mathematically, the definition is that for all values of θ a *constant* value α can be found, so that $f(\theta) = f(\theta + \alpha)$. In the working which follows we set the co-ordinate scale so that $\alpha = 2\pi$.

Odd and Even Harmonics.

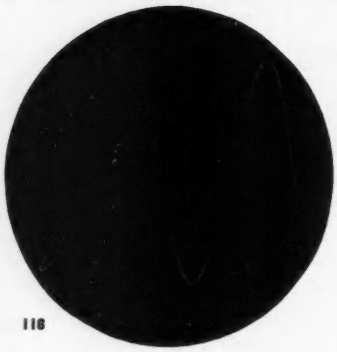
A harmonic is the name given to each component term forming the resultant complex wave. A harmonic is *odd* if its k in Equation (45)† is odd, and *even* if its k is even. Thus the first harmonic (*i.e.*, the fundamental) is odd since $k = 1$, and the second harmonic is even since $k = 2$, etc.

(*Continued on p.* 116.)

* I am greatly indebted to the stimulating account of R. G. Manley on these matters in his book "Waveform Analysis" (Chapman & Hall, Ltd.).

† The equations have been numbered serially throughout these articles for convenient reference—ED.

Complex Waveforms — 2nd Harmonic Distortion. *(Note all waves are non-alternant)*

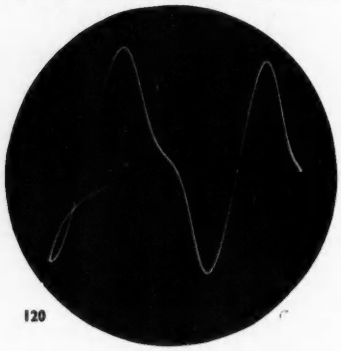


118

$$A \sin \theta + \frac{A}{10} \sin 2\theta.$$

119

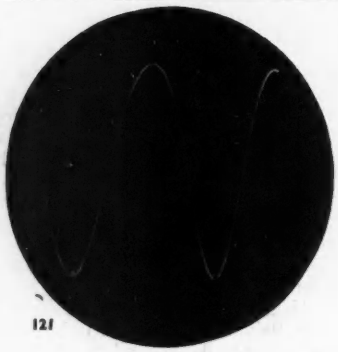
$$A \sin \theta + \frac{A}{5} \sin 2\theta.$$



120

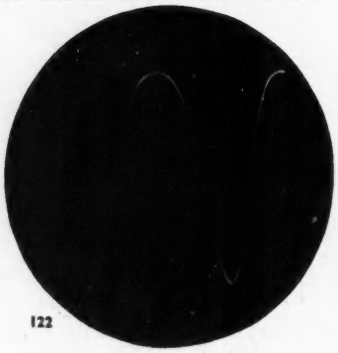
$$A \sin \theta + \frac{2}{5} A \sin 2\theta.$$

Waves in Figs. 118 119, 120, are skew-symmetrical about 0, π, etc., hence they involve no cosine terms.



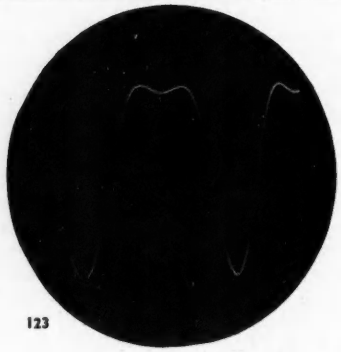
121

$$A \sin \theta + \frac{A}{10} \sin\left(2\theta + \frac{\pi}{2}\right) = A \sin \theta + \frac{A}{10} \cos 2\theta.$$



122

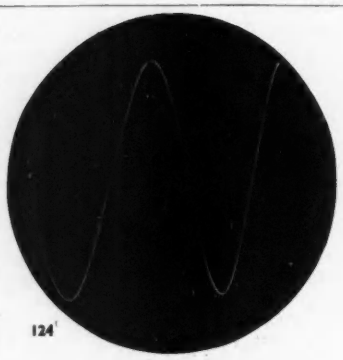
$$A \sin \theta + \frac{A}{5} \sin\left(2\theta + \frac{\pi}{2}\right) = A \sin \theta + \frac{A}{5} \cos 2\theta.$$



123

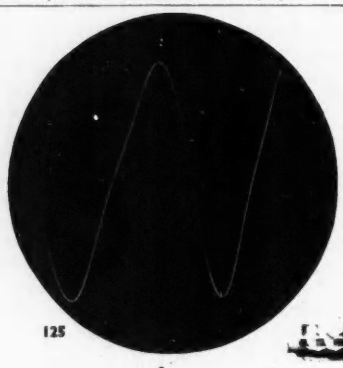
$$A \sin \theta + \frac{2}{5} A \sin\left(2\theta + \frac{\pi}{2}\right) = A \sin \theta + \frac{2}{5} A \cos 2\theta.$$

Waves in Figs. 121, 122, 123, are not skew or normal y symmetrical about 0, π, etc., hence they involve both sine and cosine terms. Symmetry about $\pi/2$ would permit expression with cosine terms only by shift of origin.



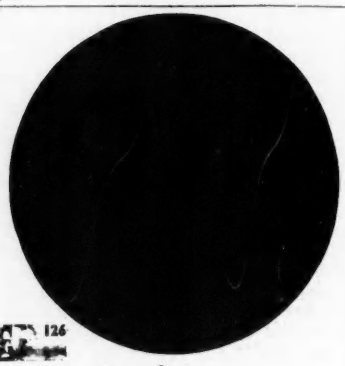
124

$$A \sin \theta + \frac{A}{10} \sin(2\theta + \pi) = A \sin \theta - \frac{A}{10} \sin 2\theta$$



125

$$A \sin \theta + \frac{A}{5} \sin(2\theta + \pi) = A \sin \theta - \frac{A}{5} \sin 2\theta$$

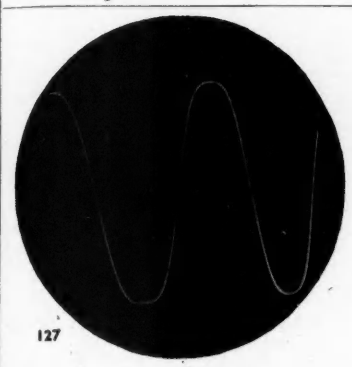


126

$$[A \sin \theta + \frac{2}{5} A \sin(2\theta + \pi) = A \sin \theta - \frac{2A}{5} \sin 2\theta$$

Waves in Figs. 124, 125, 126 are skew-symmetrical about 0, π, etc., hence they involve no cosine terms.

Complex Waveforms — 3rd Harmonic Distortion. *(Note all waves are alternant)*

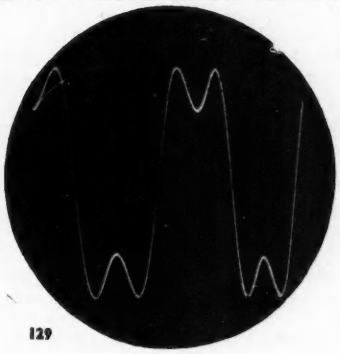


127

$$A \sin \theta + \frac{A}{10} \sin 3\theta$$

128

$$A \sin \theta + \frac{A}{5} \sin 3\theta$$



129

$$A \sin \theta + \frac{2}{5} A \sin 3\theta$$

Waves in Figs. 127, 128, 129, are alternant, skew-symmetrical about 0, π, etc., hence they *must* also be symmetrical about $\pi/2$, etc. Hence they contain only *odd* sine terms.

130

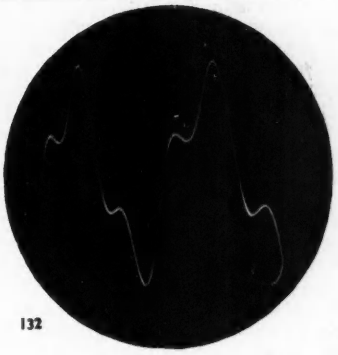
$$A \sin \theta + \frac{A}{10} \sin \left(3\theta + \frac{\pi}{1}\right)$$

$$= A \sin \theta + \frac{A}{10} \cos 3\theta$$

131

$$A \sin \theta + \frac{A}{5} \sin \left(3\theta + \frac{\pi}{2}\right)$$

$$= A \sin \theta + \frac{A}{5} \cos 3\theta$$

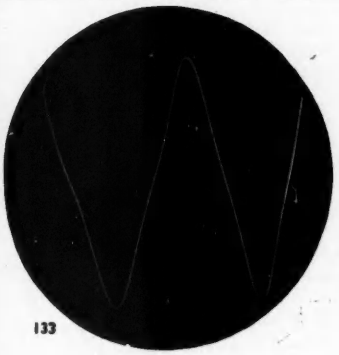


132

$$A \sin \theta + \frac{2}{5} A \sin \left(3\theta + \frac{\pi}{2}\right)$$

$$= A \sin \theta + \frac{2}{5} A \cos 3\theta$$

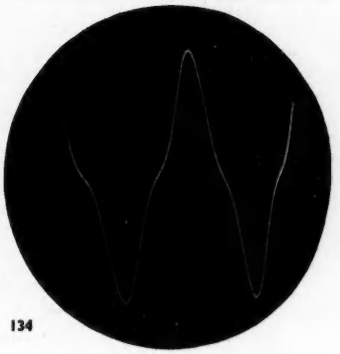
Waves in Figs. 130, 131, 132, display only alternance and no other form of symmetry. Hence waves involve both sine and cosine terms but only *odd* coeffs.



133

$$A \sin \theta + \frac{A}{10} \sin (3\theta + \pi)$$

$$= A \sin \theta - \frac{A}{10} \sin 3\theta$$

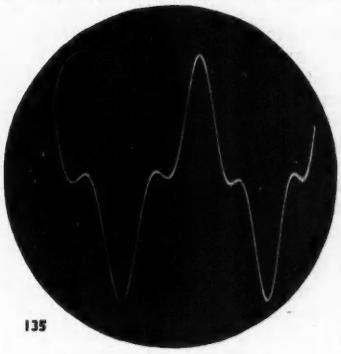


134

$$A \sin \theta + \frac{A}{5} \sin (3\theta + \pi)$$

$$= A \sin \theta + \frac{A}{5} \sin 3\theta$$

As for Figs. 127, 128, 129.



135

$$A \sin \theta + \frac{2}{5} A \sin (3\theta + \pi)$$

$$= A \sin \theta - \frac{2}{5} A \sin 3\theta$$

Axes of Wave.

Rectangular Cartesian co-ordinates are used. The angle is plotted along the horizontal X axis, the wave amplitude along the Y axis. Since we almost invariably deal with waves of constant frequency, the X axis can be regarded as a linear time axis.

Wave Symmetry

A recognition of symmetry (if any) is fundamental in wave analysis. There are three distinct types of wave symmetry, illustrated in Figs. 1(a), 1(b) and 1(c).

(*a*) *Alternance.*

This is shown in Fig. 1(a). Here the negative half-cycle is an exact copy of the positive half-cycle. Mathematically the condition for alternance is:

$$f(\theta) + f(\theta + \pi) = 0 \quad \ldots\ldots\ldots\ldots \quad (46)$$

for all θ.

(*b*) *Normal Symmetry.*

As shown in Fig. 1(b). The wave is symmetrical about some value of θ, say $\theta = \alpha$. Hence the condition is:

$$f(\alpha - \theta) = f(\alpha + \theta) \quad \ldots\ldots\ldots\ldots \quad (47)$$

(*c*) *Skew Symmetry.*

This is shown in Fig. 1(c). This is what was previously termed *reflected symmetry* (August issue, Part 1, 1944). The condition is:

$$f(\alpha - \theta) = -f(\alpha + \theta) \quad \ldots\ldots\ldots \quad (48)$$

being identical with condition (47) except for change of sign. Hence the term "reflected symmetry."

"Disguised Symmetries"

It should be noted that the symmetries of 1(a) and 1(c) may be disguised if these waves are not balanced about the zero line OX. This corresponds merely to a shift of the horizontal coordinate axis. It is clear that the fundamental symmetry properties of the curves cannot be altered by such a shift, although the definitions of their nature given by (46) and (48) are now in error. In what follows it will be assumed that the reference axes are so placed before the analysis commences that the areas of the positive and negative half-cycles are equal. This corresponds to making the constant a_0 in (45) equal to zero.

Deductions from Symmetry Conditions.

We commence by stating a theorem which is almost self evident:

Any symmetry property exhibited by a complex wave must also be exhibited by all the components of that wave and conversely:

If all the component waves exhibit a certain symmetry property, then the resultant complex wave must also exhibit the same symmetry property.

Consider the following fundamental property of circular functions:

$$\begin{matrix}\cos\\ \sin\end{matrix}(2k+1)\theta = -\begin{matrix}\cos\\ \sin\end{matrix}(2k+1)(\theta+\pi) \quad \ldots\ldots\ldots \quad (49)$$

and

$$\begin{matrix}\cos\\ \sin\end{matrix}2k\theta = \begin{matrix}\cos\\ \sin\end{matrix}2k(\theta+\pi) \quad \ldots\ldots\ldots\ldots \quad (50)$$

where k is any integer.

It is apparent that (49) satisfies the condition for alternance defined by (46), for all values of k. Hence the resultant wave composed only of *odd* harmonics ($2k + 1$ is always odd) is alternant, and *vice versa.* Any even harmonic must satisfy (50) which does not satisfy (46), so that *in an alternant wave no even harmonics can be present, and vice versa.*

Another important property of the circular functions is expressed by:

$$\cos(k\pi + \theta) = \cos(k\pi - \theta) \quad \ldots\ldots (51)$$

$$\sin(k\pi + \theta) \neq \sin(k\pi - \theta)$$

where k is any integer.

Thus if a wave displays normal symmetry about $\theta = 0, \pi$, etc., it follows from condition (47) that the wave contains only cosine components. Note that if a wave displays normal symmetry about $\theta = 0$, it must also display normal symmetry about any integral multiple of π.

Similarly, since

$$\sin(k\pi + \theta) = -\sin(k\pi - \theta) \quad \ldots\ldots (52)$$

$$\cos(k\pi + \theta) \neq -\cos(k\pi - \theta)$$

*a wave which possesses skew symmetry about 0, etc., cannot contain any cosine components.**

The following two theorems are readily established: "If a wave is symmetrical about 0, π, etc., the only values about which it can be skew symmetrical are given by $k\pi/2$ where k is any integer," and "Any wave which exhibits any two of the symmetry properties defined, must also possess the third.

In applying these results to waves in general the axes must be so chosen that the symmetry property is exhibited about 0, $\pi/2$, etc. This is readily achieved in all cases. Table 1 summarises the conclusions to be drawn from the nature of the symmetry.

Table 1. Deductions from Wave Symmetry

Type of Symmetry present in Wave	Harmonic Terms
Alternance	Only odd sine and odd cosine
Normal symmetry about 0, π, etc.	Only cosine
Skew symmetry about 0, π, etc.	Only sine
Alternance and normal symmetry about 0, π, etc. (Note this wave must also display skew symmetry about $k\pi/2$.)	Only odd cosine
Alternance and skew symmetry about 0, π etc. (Note this wave must also display normal symmetry about $k\pi/2$.)	Only odd sine

The reader should apply the theory of symmetry to the curves (Figs. 118-135) to verify the conclusions of Table 1.

Experimental Technique

A block diagram of the circuit used is given in Fig. 2. (Full details of all these circuits will be given in later appendices.) Note the method of displaying two cycles of the complex wave, by using the second harmonic of the master oscillator as the fundamental frequency of the synthesised wave, but deriving the time base discharge pulse from the master oscillator itself.

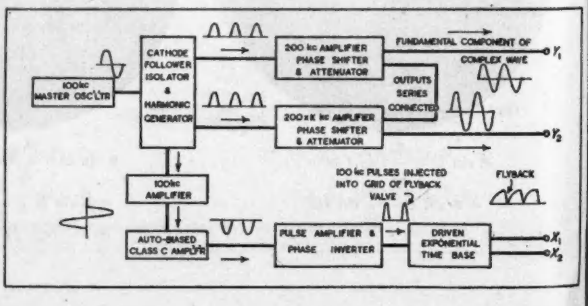
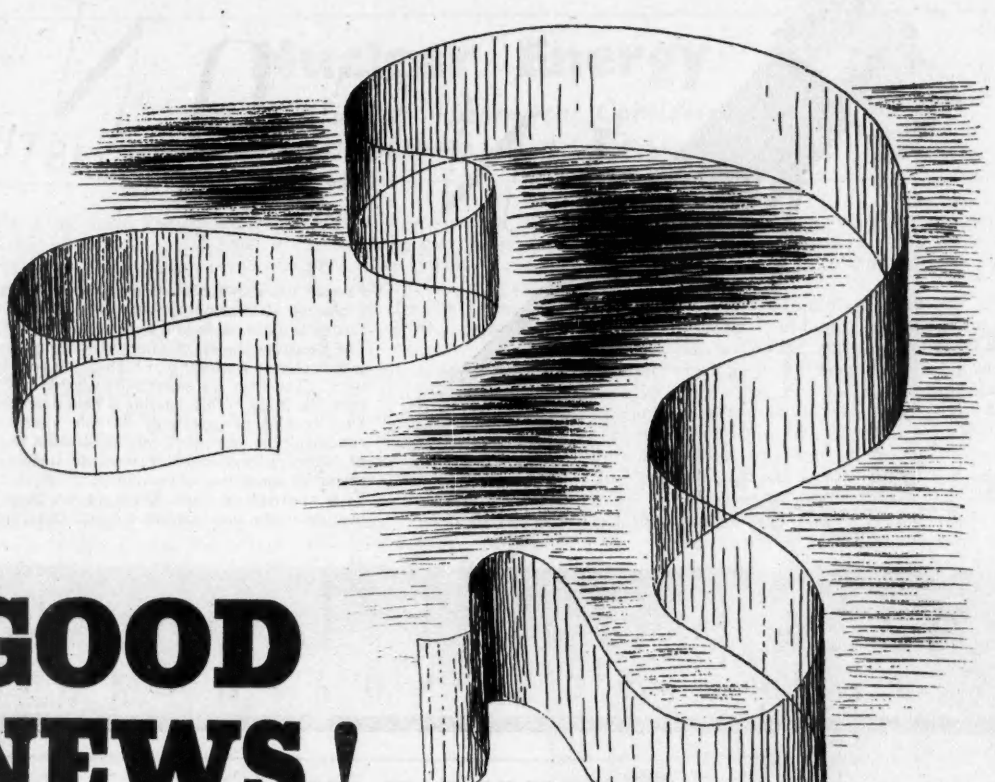


Fig. 2. Block circuit diagram of Harmonic Synthesiser

Reference

1 "The Short Time Constant Circuit," M. G. Scroggie, *Wireless World*, Dec., 1945.

* When we say "cannot contain any cosine components" we are, of course, referring to the expansion of $f(\theta)$ in the form indicated in Eqt. (45). It is always possible to introduce cosine terms by bringing in a phase angle, since $\sin\theta = \cos(\frac{1}{2}\pi - \theta)$. The same meaning must be attached to the phrase "cannot contain any sine terms."



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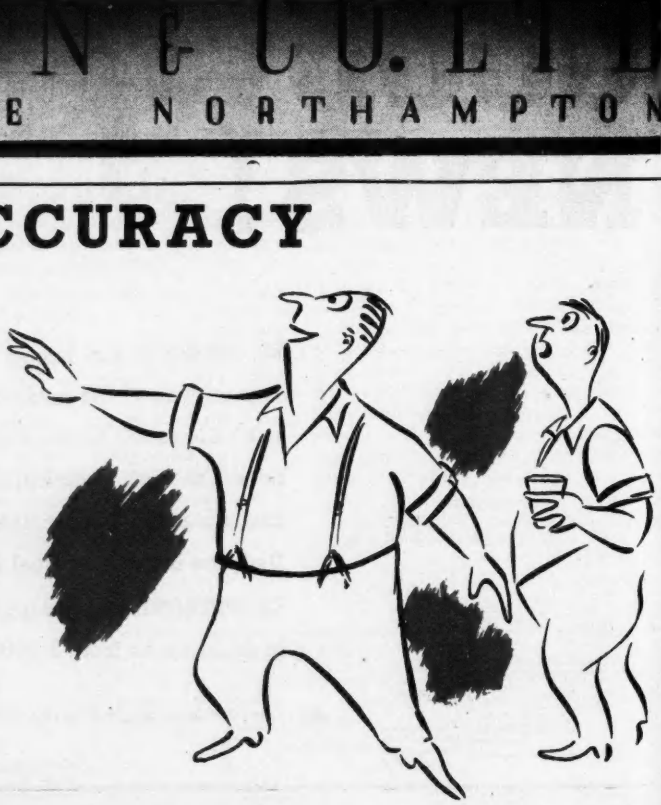

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Nuclear Energy

PART II.—Further Theoretical Considerations

By W. D. OLIPHANT, B.Sc., F.Inst.P.

IN Part I we have considered the properties of atomic nuclei from a particle, mass and charge point of view and have examined the binding energy which becomes manifest during nuclear synthesis or fission. Nuclei possess certain other properties involving energy which are of considerable importance in the study of radioactive emission and in the effective bombardment by sub-atomic charged particles. While at first sight it might seem inappropriate to include under the heading of the present series any matter relating to the properties associated with the extra-nuclear electrons, it nevertheless provides us with valuable knowledge concerning the most probable mechanism of nuclear behaviour and so we will review present theories relating to the atom as a whole.

The Quantum Theory

The quantum theory was introduced by Planck, who observed that energy regarded as a continuum was inadequate to explain the continuous spectrum of black-body radiation, it was necessary to introduce the hypothesis that energy was emitted and absorbed discontinuously in multiples of a single unit or *quantum*, the magnitude (ϵ) of which was given by

$$\epsilon = h.\frac{c}{\lambda} = h\nu \quad \ldots\ldots\ldots\ldots\ldots (1)$$

where λ and ν are respectively the wavelength and frequency of the radiation; c is the velocity of light in vacuo (3×10^{10} cm. sec^{-1}), and h is a constant known as Planck's constant or the action constant (6.62×10^{-27} erg./sec.).

The success of the quantum theory led Einstein to suggest that not only was radiation emitted and absorbed in quanta, but that it was actually propagated through space with the velocity of light in definite quanta or *photons* whose energy was again given by Equation (1). Experimental confirmation of this was readily derived from his classical experiments on the photo-electric effect, and was later applied to explain the Compton effect.

The observations made on the series line spectra of atomic hydrogen, when taken in conjunction with the concept of energy quanta, led Bohr to the conclusion that the spectral lines arose from extra-nuclear electron transitions within the atom from states of higher to those of lower energy levels. According to the Ritz combination principle, the frequency (ν) of any spectral line in the series was always given by the difference between two frequency terms, and so, if this relation was multiplied by h, then the resulting energy equation took the form:

$$h\nu = W_1 - W_2 \quad \ldots\ldots\ldots\ldots\ldots (2)$$

where W_1 and W_2 represent the energies associated with two states within the extra-nuclear structure of the atom.

Bohr postulated that an atomic system could only exist permanently in a certain series of discontinuous energy levels and that monochromatic emission or absorption of radiant energy could only arise as the result of a complete electron transition between two such states. The number of such states was determined by the quantum condition that the angular momentum (mvr) of the electron be an integral multiple of $h/2\pi$. The possible orbits, here assumed for the

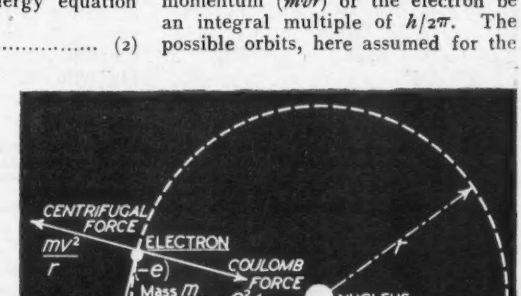


Fig. 1. Simple electro-mechanical model of the hydrogen atom.

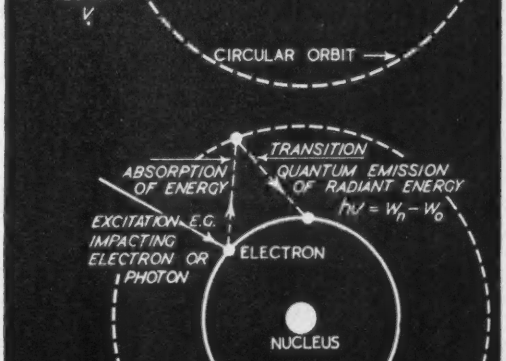


Fig. 2. Mechanism of extra-nuclear electron transition.

The planetary electron originally in the normal (unexcited) orbit receives additional energy from the mode of excitation and is displaced into an excited orbit. The electron then falls back into the normal orbit with the attendant emission of a quantum of radiant energy. If the excitation energy exceeds the difference in energy between the highest excited orbit and the normal orbit, then the planetary electron is forced out of the atom and the atom is then said to be ionised.

sake of simplicity to be circular of radius r, are thus given by the quantised momentum relationship:

$$mvr = n.\frac{h}{2\pi} \quad \ldots\ldots\ldots\ldots \quad (3)$$

where n is known as the quantum number of the particular energy level.

In a simple model of the hydrogen atom, the orbits are assumed to be circular and centred on the nucleus as shown in Fig. 1.

The electron is thus subjected to two forces, the Coulomb force of attraction (e^2/r^2) between nucleus and electron, and the centrifugal force (mv^2/r) due to its circular motion. For space equilibrium these forces must be equal, thus:

$$\frac{mv^2}{r} = \frac{e^2}{r^2} \quad \ldots\ldots\ldots\ldots \quad (4)$$

It is thus possible, on eliminating the linear electron velocity (v) between Equations (3) and (4), to obtain an expression for the orbital radii; thus for the hydrogen atom ($Z = 1$)

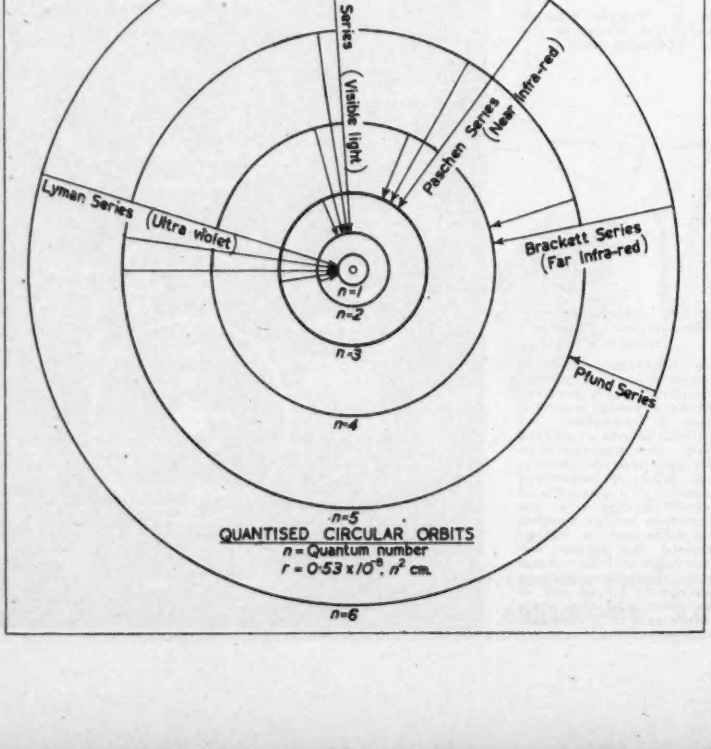
$$r = \frac{h^2}{4\pi^2 me^2}.n^2 = \text{constant} \times n^2 \quad (5)$$

In other words the possible radii are proportional to the square of the quantum number, and the first orbit for hydrogen ($n = 1$) is found to be equal to 5.3×10^{-9} cm.

According to classical electromagnetic theory, radiation can only arise as the result of accelerative motion of electric charges, and, since the Bohr model includes electrons moving in circular orbits, it was necessary to postulate that the attendant centripetal acceleration did not give rise to radiation; radiation only arose as the result of acceleration during transitional motion as a consequence of suitable excitation. The mechanism of radiation is shown in Fig. 2, while the transitions associated with the familiar hydrogen series spectra are shown in Fig. 3.

Modern development of the quantum theory as such holds that the precise orbital behaviour or configuration is unknown and need not necessarily be circular, but atomic characteristics nevertheless must comply with the quantised energy conditions which arise as the result of the model whose geometry has just been developed. Such energy conditions have been found to agree with the earlier empirical analysis of line spectra and with the later observations of such phenomena as resonance absorption and radiation of energy. In general, if an atom is exposed to conditions involving absorption of energy (excitation) such as by the use of a high temperature or in an electrical discharge, the electrons will take up energy and pass from an inner to an outer orbit, the amount of energy involved being exactly equal to the difference between the two levels. The electrons will then return to their normal orbits with the emission of radiation quanta.

Fig. 3. Line spectral series for atomic hydrogen. The arrows show the electron transitions appropriate to the formation of the known series of spectral lines. Any one atom at any instant can emit only one photon of radiation, but due to the pressure of a volume of hydrogen all lines appear simultaneously.



Particles and Waves

In the study of radiation (such as light) propagational phenomena, such as interference, diffraction and polarisation, can only be explained on the basis that a beam of light consists of a train of waves. When, however, radiation interacts with matter (as in the photo-electric and Compton effects), then an atomistic or corpuscular quality must be admitted—the energy arrives in definite measures known as photons. Now we have already seen the equivalence which exists between energy and mass, and so if m be the equivalent mass of a photon which travels with velocity c, then

$$mc^2 = h\nu$$

or the momentum of the photon is given by:

$$p = mc = \frac{h\nu}{c} = \frac{h}{\lambda} \quad \ldots\ldots\ldots\ldots \quad (6)$$

The dualism of the wave and particle aspects of radiation led de Broglie to suggest that a similar dualism might exist for such material particles as electrons, protons and neutrons.

Thus an electron possessing momentum (mv) will have associated with it a wave whose length is given by:

$$\lambda = \frac{h}{mv} \quad \ldots\ldots\ldots\ldots \quad (7)$$

In other words, associated with a material particle in motion we have a hypothetical *matter wave* as defined by Equation (7). The particle velocity (v) is also the group velocity of the matter wave while the wave (or phase) velocity (u) is obtained from the relation:

$$uv = c^2 \quad \ldots\ldots\ldots\ldots \quad (8)$$

Since the particle velocity can never exceed that of light, nor be equal to it, it follows that the matter

wave phase velocity (u) is always greater than that of light; this condition shows that matter waves differ fundamentally from the electromagnetic radiation waves.

The wave nature of electrons in motion has ample experimental confirmation in the classical electron diffraction experiments of Davisson and Germer and of G. P. Thomson.

The correlation of wave and particle properties gives rise to the uncertainty principle of Heisenberg which is accepted as one of the fundamental principles of modern physical theory. According to this, any experiment involving a knowledge of the velocity of the particle, such as in the determination of energy, requires the particle concept, while any experiment involving position requires the wave concept—the simultaneous determination of velocity and position is impossible since wave and particle aspects are not manifest at one and the same time or with a particular experimental set-up.

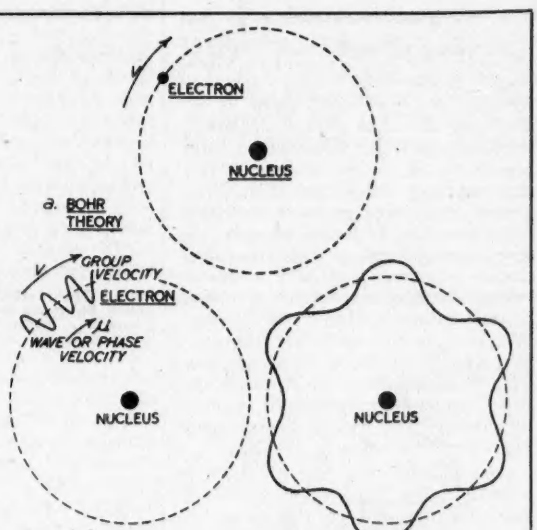


Fig. 4. Comparison between atom models based on the Bohr electro - mechanical theory and on the Schrödinger wave-mechanical theory.

The Wave-Mechanical Model of the Atom

Having established the fact that electrons in motion have associated with them a wave motion in accordance with Equation (7), it is fitting that we should reconsider the mechanism of the extra-nuclear electrons of the atom in this light. Heisenberg developed the subject mathematically (by matrix mechanics) without recourse to an atomic model, while Schrödinger developed a system of *wave mechanics* which can be applied to the model already described, and which yields basic energy values in complete accord with the Bohr values.

The wave-mechanic condition requires that when an electron moves in, say, a circular orbit round the parent nucleus, the associated wave train must extend round the orbit and remain continuously in phase; in other words the circumference ($2\pi r$) must be an integral multiple (n) of complete wavelengths, thus:

$$2\pi r = n\lambda = \frac{nh}{mv} \quad \ldots\ldots\ldots\ldots (9)$$

from which it is readily seen that the angular momentum is again equal to $nh/2\pi$, in complete accord with the Bohr quantised momentum condition as expressed in Equation (3).

Comparative models based on the two theories are shown in Fig. 4.

The present picture serves to give a first insight into the kind of properties involved and it must be understood that, in practice, a three-dimensional wave system is called for.

Each energy level may be regarded now as a proper mode of vibration requiring that stationary waves be set up in the orbit in analogous fashion to the discrete vibrational modes which are set up in an acoustical or electrical system with a given set of boundary conditions and excitation. The precise medium capable of supporting or propagating such matter waves is, like the ether of space, purely hypothetical and of no practical significance.

In the wave theory of the hydrogen atom, a stationary state is thus regarded as a proper mode of vibration set up under certain boundary constraints and the displacement (D) at any point is a periodic time function of the form:

$$D = \psi \sin\omega t \quad \ldots\ldots\ldots\ldots (10)$$

where ω is the pulsatance and ψ is the amplitude at any point in space, ψ being a function of space co-ordinates.

Arising out of this stationary wave equation, Schrödinger developed his wave equation for the wave-mechanical treatment of a moving electron possessing three degrees of freedom, thus:

$$\nabla^2\psi + \frac{8\pi^2 m}{h^2}(W - E\rho)\psi = 0 \quad \ldots\ldots (11)$$

where W is the *total* energy of the electron, $E\rho(= -e^2/r)$ is the potential energy, and ∇^2 is the Laplacian operator. When certain definite boundary conditions are prescribed, the solutions to the above equation have physical significance for definite values of energy (W) and such values are found to agree with those of Bohr. ψ must be periodic, continuous and single-valued, vanishing asymptotically for large values of r and for $r = 0$; it represents the probability of finding an electron in a particular place, and it is obvious that this must decrease as r increases, as well as for r equal to zero, for then the electron would actually be within the nucleus itself.

The forms of ψ corresponding to definite values of W are known as *wave functions* and they are the wave-mechanical equivalent of the Bohr orbits. The physical significance of such functions was described by Schrödinger on the assumption that ψ^2 at any point was a measure of the electric charge density at that point—the electron was, so to speak, spread out in such a manner that the spatial charge distribution varied from place to place.

On both the Bohr and Schrödinger theories, the energy values are given in the usual notation by:

$$W = -\frac{2\pi^2 m e^4}{h^2 n^2} \quad \ldots\ldots\ldots\ldots (12)$$

The Bohr orbits on the new quan-

tum mechanical theory have no real existence, their place now being taken by stationary quantised vibrational modes. In such states ψ^2 remains constant and there is no radiation since the charge density is stationary. Due, however, to the absorption of energy, ψ is no longer constant and must vary with time, hence ψ^2 also varies with resulting radiation. In order to explain the line spectral series, it is necessary that at least two stationary modes be excited simultaneously to give rise to two distinct radiations which then beat to give the resulting frequency characteristic of the emitted radiation. This is in complete accord with the Ritz combination principle already referred to, and with the corresponding energy equation at (2).

Perhaps the only real difficulty in forming a mental picture of the wave-mechanical model of the atom lies in the necessity to spread out the electron into a kind of electric vapour. This led Bohr to introduce another conception of the quantity ψ involving the statistical interpretation that the quantity ψ^2 represent the *probability* of finding an electron (again regarded in this sense as a discrete particle) at a given point at a given time.

By whatever method the atom model is developed it is found that complete agreement exists not only between methods (essentially theoretical in nature), but also with the observations of experiments. While it is possible to grasp the physical significance of most of the theoretical implications involved it is nevertheless extremely difficult to form a mental picture of the "energy mechanism" within the atom.

Nuclear Energy States

The α-, β- and γ-rays which are emitted from the nuclei of radioactive atoms may justifiably be regarded as arising from energy levels within the nucleus itself. The α-rays comprise doubly ionised helium atoms or helium nuclei, while the β-rays are fast-moving electrons—both are corpuscular in nature, possess an electric charge and can thus be deflected by a magnetic field. γ-rays, on the other hand, are unaffected by a magnetic field, but present properties similar to those of X-rays and so they too must obey normal quantum conditions for radiation.

In the earlier theory of γ-ray emission, it was assumed that they were generated either as the result of a sudden arrest of α- or β-rays within the mass of the radioactive substance, or by the sudden ejection of such particles from a nucleus—in either case the acceleration of an ejected charged particle was held to be the cause of this form of radiation. It is now held that the origin of γ-rays is due in very large part to the existence of nuclear energy levels.

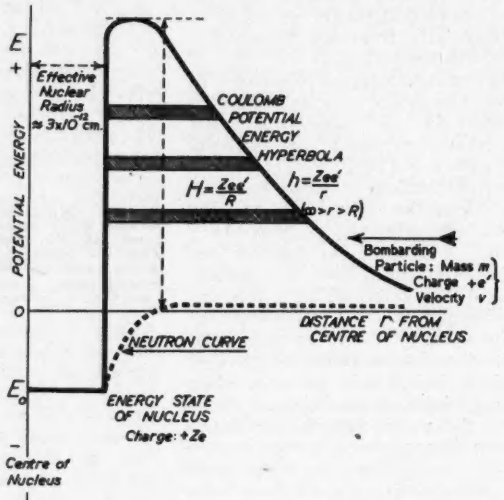


Fig. 5. The nuclear model based on the "potential barrier" concept.

The fact that electrons are emitted from the nucleus in the course of radioactive disintegration indicates that they must form part of the nucleus, and in all probability the neutrons are produced by the close association of a proton and an electron.

The nuclear protons and electrons are assumed to exist in quantised states so that after the emission of an α- or β-particle, the remaining nuclear particles are in an excited state. This energy level is higher than the normal (lowest) energy level of the nucleus which has just been formed and so a readjustment takes place involving a transition with attendant emission of a quantum of γ-radiation. This process will continue till the lowest energy state has been reached. In view of the fact that radioactivity is spontaneous in nature and cannot be controlled by any external means short of drastic bombardment, the nucleus does not present absorption properties similar to the extra-nuclear electron system.

The Model Nucleus

Experiments on nuclear bombardment have shown that positively charged bombarding particles such as α-particles, protons and deuterons are most effective against the lighter atoms, while their effect increases rapidly with their energy. Neutrons, on the other hand, are most effective against heavy atoms, especially when slowed down. It should, therefore, be possible to construct a model in the mind which will enable such behaviour to be readily understood.

We have already seen how the nucleus is made up of protons and neutrons which may be regarded as occupying a sphere whose diameter is of the order of 10^{-12} cm. Within this volume, positively charged particles can reside without repelling each other, but, in the light of Rutherford's classical experiments on the nuclear scattering of α-particles, it is evident that the normal Coulomb law of force exists down to a distance of the order of 3×10^{-12} cm. from the centre of the nucleus. The region centred around the nucleus must therefore present a special field configuration which permits of a sudden discontinuity in the normal law of force.

Let us assume that the nuclear charge is $+ Ze$, then at some distance r from the centre of the nucleus ($r > 3 \times 10^{-12}$ cm.), the potential is given by Ze/r. A particle of mass

m and charge $+ e'$ is approaching the nucleus with velocity v, then the potential energy of the particle will increase as the distance from the nucleus decreases. This potential energy must be supplied at the expense of its initial kinetic energy of translation, and so if d be the distance of nearest approach to the nucleus, then:

$$\frac{Zee'}{d} = \tfrac{1}{2}mv^2$$

from which $d = \dfrac{2Zee'}{mv^2}$ ..... (10)

Thus for a bombarding particle endowed with a given amount of kinetic energy, the distance of nearest approach will decrease as the value of Z decreases; in other words such particles will be more effective in breaking into the lighter nuclei. This is in complete agreement with earlier observations which, of necessity, had to be made with the fixed energy particles derived naturally from radioactive substances. It is now possible, by means to be described in Part III, to accelerate artificially nuclear projectiles and so impart to them high orders of kinetic energy.

Within a distance of the order of 3×10^{-12} cm., the potential energy must decrease rapidly due to the evident attraction between nuclear particles and assume some constant value E_0 which may be either positive or negative. In general, the value is negative, thereby conforming to the necessary condition for stability in a physical system. Fig. 5 shows the form of the potential energy curve as a function of distance r from the centre of the nucleus.

This curve is generally referred to as the nuclear *potential barrier* and it may be regarded as a shell surrounding the nucleus through which bombarding particles must pass to be captured; the nucleus is thus protected by an "energy shell." The maximum ordinate H (at distance R) represents the maximum potential energy which must be reached before a bombarding particle can pass "over" the barrier into the nucleus. It should be realised that the particles do not in fact pass *over* the barrier like a golf ball passing over a mound into a hole (an analogous example in the gravitational field), but they actually go straight for the nucleus under the influence of the repulsive force which slows down the motion, and, if the kinetic energy is at least not equal to H, the particle will be sent back again with its original energy.

It has been found in experiments on nuclear disintegration by bombardment that some particles can actually penetrate the potential barrier at energy levels less than H—such energy levels are shown hatched in Fig. 5 and may be looked upon as "tunnels." There is thus a distinct *probability* that a positively charged bombarding particle whose kinetic energy is less than the height of the potential energy barrier can penetrate the wall and such a probability is calculated on the theory of wave mechanics.

The frequency of penetration of the potential barrier is given by the square of the standing wave amplitude (ψ^2) and this must clearly diminish with increasing "thickness" of the barrier wall. Thus high-energy particles have a higher probability factor for penetration at levels less than H than do lower energy particles. Such "tunnel" energy levels are known as *resonance energies*, and a projectile making use of such tunnels is said to suffer resonance capture.

To an uncharged particle such as a neutron there is no potential barrier and hence even very slow neutrons (low energy) can penetrate a nucleus without any trouble. They suffer, in fact, a mild attractive force at distances greater than R due to **polarisation**. A neutron "energy path" is shown dotted in Fig. 5.

The wave-mechanical solution suggested to Gamow that bombarding particles need not acquire beforehand energies at least equal to H to penetrate into a nucleus, and this has provided for disintegration experiments being successfully carried out with moderate velocity particles, a factor which is of some considerable importance in the design of accelerators of high-energy atomic projectiles.

The Electron-Volt

The unit of energy adopted in nuclear physics is the electron-volt, and it is the amount of energy equal to the kinetic energy imparted to an electron which falls through a potential of 1 V. When a particle or a vibration has energy equal to the kinetic energy possessed by an electron which has fallen through V volts, the particle or vibration is said to have an energy of V electron-volts (eV):

1 electron-volt = 1.6×10^{-12} erg.

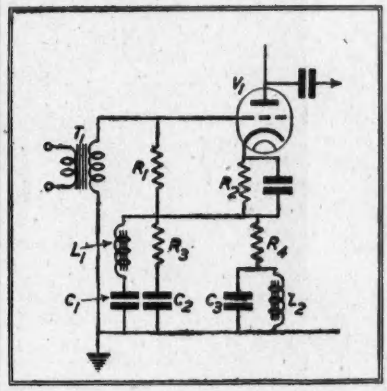
(To be continued.)

Corrections

High Fidelity Bass Compensation

It is regretted that an error, for which the author was not responsible, occurred in Fig. 1 of the article on Bass Compensation (p. 45, February issue).

This shows the lower end of the transformer secondary connected to L_1, whereas it should be connected to earth as shown in the diagram below.



Apologies to the author for this slip, and thanks to numerous readers who have written to point it out.

Marconi Instruments, Ltd.

In the list of Classified Products in the Physical Society's Exhibition Report (p. 41, February issue), the name of Marconi Instruments, Ltd., in one or two cases is wrongly classified, and is, unfortunately, omitted from the most important heading under which they should appear: "Electrical Testing and Measuring."

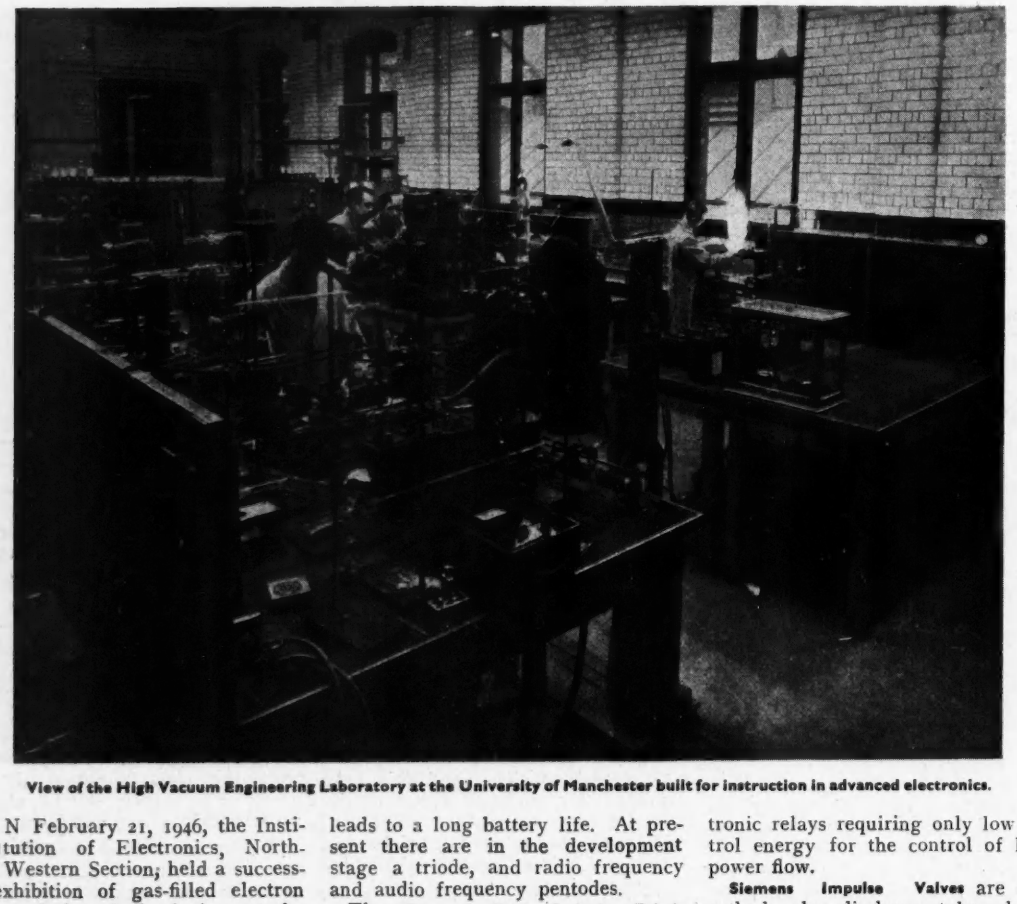
The company inform us that they do not manufacture Crystals or Small Motors, but should be included in the manufacturers of Thickness Testers.

The activities of Marconi Instruments, Ltd., are so well known that readers will no doubt have made the correction already.

Please mention
ELECTRONIC ENGINEERING
when replying to advertisers

Reports on EXHIBITIONS

1. Institution of Electronics, Manchester



View of the High Vacuum Engineering Laboratory at the University of Manchester built for instruction in advanced electronics.

ON February 21, 1946, the Institution of Electronics, North-Western Section, held a successful exhibition of gas-filled electron tubes and thermionic devices at the electro-technical laboratories of the university in which several firms, mainly from the north-western area, participated. This report covers only a few items of the large number of interesting exhibits.

Electronic Circuit Elements

The **Cossor Fuse-type Vacuum Tubes** which are of the same type as used in proximity fuses by the Services, are 10 mm. diameter and 26 mm. length. They are mechanically strong, need no bases and have commercial uses including hearing-aids and miniature personal receivers; the filament consumption of 30 mA only leads to a long battery life. At present there are in the development stage a triode, and radio frequency and audio frequency pentodes.

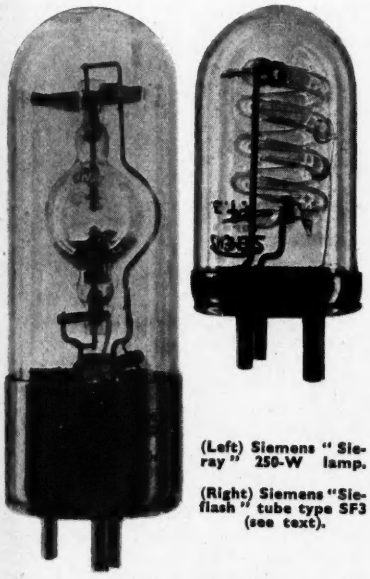
The **Ferranti Cold Cathode Triode** type K3 is designed for an anode voltage of 130-140 volts and a triggering voltage of about 80 volts at a triggering current of approx. 4 micro-amps. For operation as an electronic relay a static bias voltage up to 75 volts may be applied in the triggering circuit.

B.T.H. Steel Water-cooled Type Ignitrons are capable of carrying heavy peak currents as occur in the electronic control of A.C. resistance welding machines. The introduction of a shield-grid in the thyratron-type gas-filled tubes gives an improved control-characteristic for the tubes which are essentially used as electronic relays requiring only low control energy for the control of large power flow.

Siemens Impulse Valves are cold-cathode glow-discharge tubes characterised by having stable ignition and extinction voltages and a conductivity which makes them suitable for the operation of relay devices, such as timing control circuits, *e.g.*, in automatic traffic control units. The operation of such a unit was demonstrated.

The **Siemens Gas-filled Surge Protectors** are cold-cathode gas-discharge devices of such a design as to enable heavy currents to pass for short periods. This makes the device suitable for the protection of electrical apparatus against high-voltage surges.

EXHIBITIONS



(Left) Siemens "Sieray" 250-W lamp.

(Right) Siemens "Sieflash" tube type SF3 (see text).

Electronic Instruments

The **Cossor 448 Oscillograph** uses a double-beam cathode-ray tube provided with an optically flat face to facilitate measurements. The gain control of the signal amplifier operates by varying negative feedback. Steady D.C. voltage can be measured by inserting the voltage to be tested in place of the Y1 shift voltage and computing the deflection caused thereby with the setting of the Y1 shift control which is calibrated.

The **Ferranti "Synchrolite" Electronic Stroboscope** incorporates a neon lamp operated at a controllable frequency from a calibrated valve oscillator causing the lamp to produce high intensity flashes ranging from about 500 to 15,000 per minute.

Electronic Technique

The **Cossor Sheridan Telautograph** makes use of cathode-ray tubes for the telecommunication of graphic intelligence, *i.e.*, handwriting or sketching. A complete system for two-way communication via a common cable line was demonstrated. The transmitter unit contains a metal plate on which the subject matter is inscribed by hand with the aid of a style, resulting in the production of signal components which are communicated to the remote receiver. The receiver unit contains a signal amplifier and a cathode-ray tube with associated power supplies. The received signals are converted into a pair of D.C. components which are applied to the "X" and "Y" plates of the cathode-ray tube. The resultant movement of the spot on the screen corresponds to the movement of the style point on the metal plate of the transmitter. The long afterglow period of the screen enables the luminous track inscribed by the spot to be viewed.

Electric Light Sources

High - pressure Mercury - vapour Lamps operate with an initial efficiency of about 45 lumens per watt and have an average life of 3,000 hours. Fluorescent powder applied to the inside surface of the bulb improves the colour of the light produced. (*G.E.C. and Siemens.*)

The **Compact Source Lamps of Siemens** operate at pressures of from 15 to 25 atmospheres and are made in sizes up to 10,000 watts with an arc brightness of from 20,000 to 100,000 stilbs. They are used for projection and optical purposes.

The **Ferranti "Crater Lamp"** is used for the transmission of photographs by land line and for photographic recording of music or speech. It is a hot-cathode tube operating with mercury vapour and containing

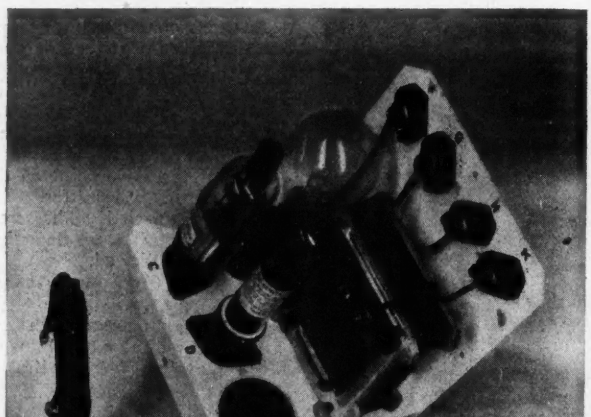
Cossor prototype model 448 metering oscillograph.

EXHIBITIONS

argon at a pressure of a few mm. Hg. The anode is a rod of tungsten surrounded by a glass tube of Pyrex. The current through the tube produces a glow at the tip of the anode rod the light intensity of which can be modulated by a corresponding variation of the current intensity. For demonstration of action the lamp was inserted in the output circuit of a Ferranti 145 receiver in place of the loudspeaker; the modulated light from the crater lamp was focused on to a photo-cell and the signal then applied to the pick-up terminals of a second 145 receiver which reproduced the music picked up by the first receiver.

High-Vacuum Technique

The **Pirani - Thyratron Vacuum Relay of Metropolitan-Vickers, Ltd.,** is used as a protective device in automatic high-vacuum equipment. By adjustment of a potentiometer the thyratron can be made to pass current from an A.C. supply, when the pressure in the Pirani gauge exceeds any desired critical value, thus making a suitable switch to operate. The Water Flow Relay operates with the differential pressure produced across an adjustable constriction by the flow of a liquid or gas. The pressure so obtained deflects flexible metallic bellows which operate an arm arranged to strike an electrical switch. The relay may be used in closed systems with pressures up to 100 lb./sq. in. to atmosphere, while the sensitivity is such that the difference between the flows to give "ON" and "OFF" indications is 5 to 10 per cent.



Metropolitan-Vickers vacuum relay (see text).

The **University of Manchester** had opened for inspection their well-equipped High-Vacuum Engineering Laboratory which was built up during the war for the purpose of instruction and research in High-Vacuum Technique and Advanced Electronics. Post-graduate students attending a current course demonstrated a variety of experiments forming part of their laboratory work. The photograph on p. 122 gives a view of the laboratory.

R. FEINBERG,
MANCHESTER UNIVERSITY.

2. R.C.M.F. Exhibition

The third exhibition of components arranged by the Radio Component Manufacturers' Federation was held at Grosvenor House, W.1, on February 19–22, 1946. Seventy-eight firms took part in the exhibition. Particulars of the Federation can be obtained from the Secretary, W. T. Ash, at 22, Surrey Street, W.C.2

Attenuators

The type AT, a stud-type attenuator, has been specially developed for volume control for power amplifiers. It has 24 studs, the standard type being 0.25 megohm in 2 db. steps. The component is sealed in a metal container with glass seal connexions.

P. X. Fox, Ltd.,
Hawksworth Road, Horsforth, Yorks.

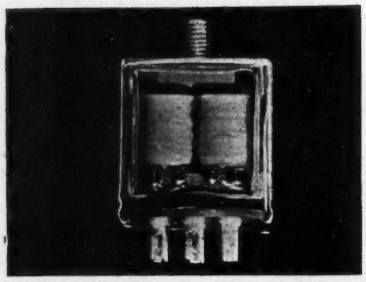
Capacitors

Paper dielectric and electrolytic capacitors for radio work, including ceramic cased tubular capacitors. Metal-cased capacitors with glass/metal terminal seals which are satisfactory for category "A" conditions —100° C. Also shown were examples of networks for radar equipment.

British Insulated Callender's Cables, Ltd.,
Norfolk House, Norfolk Street, London, W.C.1.

Ingram mycalex high-voltage capacitors; the plates are moulded solidly into the mycalex forming the dielectric. Standard types available and also types manufactured with special terminal arrangements to order.

Mycalex Company, Ltd.,
Ashcroft Road, Cirencester, Glos.



Section of binocular a.f. midget transformer— *Parmeko, Ltd*

Ceramic cased tubular capacitors were also shown by the United Insulator Co., Ltd., 12/22 Laystall Street, E.C.1. A full range of paper dielectric and electrolytic capacitors is made by the above firms and in addition by the Wego Condenser Co., Ltd., Bideford Avenue, Perivale, Greenford, Middlesex, the Telegraph Condenser Co, Ltd., Wales Farm Road, W.3, and the Dubilier Condenser Co. (1925), Ltd. Victoria Road, North Acton, W.3.

Mica capacitors ranging from 1-200,000 μF are made by the London Electrical Manufacturing Co., Ltd., Hillingdon Industrial Estate, Glasgow, S.W.2, and by the United Insulator Co., Ltd.

"Drilitic" electrolytic capacitors of extremely small size in B.R. and C.T. types. The former, having isolating sleeves, are for connecting in the wiring, while the latter are for

EXHIBITIONS

vertical mounting on chassis. A wide range of other types was also shown, including nitrogol paper dielectrics for vertical and horizontal mounting, metallised paper, ceramic trimmer, ceramic cup, disk, rod and tubular capacitors, as well as transmitting types and artificial line networks.

Dubilier Condenser Co. (1925), *Ltd.*,
Victoria Road, North Acton, London, W.3.

Concentric trimming capacitors, made of extruded aluminium with the rotor moving on a ceramic pillar, and designed for use in high Q circuits. Their lightness and small size make them suitable for use within a coil cap, for suspending in the wiring or for fixing on the chassis in conjunction with the mounting plate.

Mullard Wireless Service Co., Ltd., Century House, W.C.2.

Coils

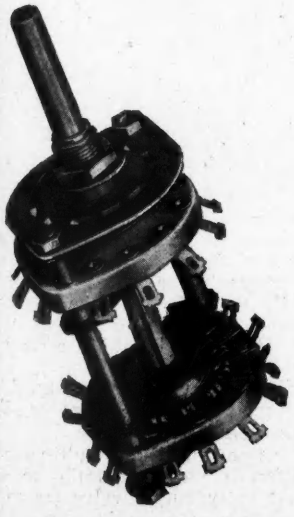
A range of air-cored coils covering 12-2,000 metres with intermediate frequency of 465 kc/s. The coils are unscreened and therefore have a higher Q than screened types. They are so constructed that they have a high degree of permanence and are relatively unaffected by climatic or atmospheric change.

Wright and Weaire, Ltd.,
High Road, Tottenham, N.17.

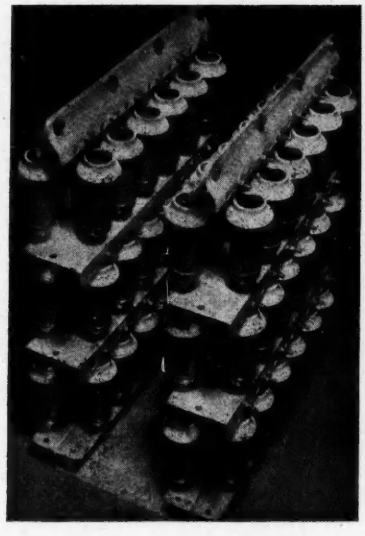
Dust Cores

"HiQor" moulded dust cores. Made of particles of ferro-magnetic materials, including flexible mica. lated from each other by plastic material and moulded to the desired shape. Coils wound on these cores have high Q values, low hysteresis factors, and small external magnetic fields. Provision is made for final accurate adjustments to be made *in situ* by inserting moulded iron dust rods into the centre of the cord and sealing into position.

Telephone Manufacturing Co., Ltd.,
Martell Road, East Dulwich, S.E.21.



Oak ceramic wafer switch.
British N.S.F. Co., Ltd.



Series parallel arrangement of ceramic high voltage capacitors (pot type).
United Insulator Co., Ltd.

Insulating Materials

Flexible electrical insulating materials to meet tropical conditions. products, varnished sleeving, varnished papers, etc. This company specialise in the production of materials, including flexible mica.

H. D. Symons and Co., Ltd.,
Park Works, Kingston Hill, Surrey.

A full range of materials shown included mica, micanite, paxolin and varnished fabrics and tubing.

Micanite and Insulators, Ltd.,
Empire Works, Walthamstow, E.17.

Insulators

Miniature low-loss stand-off insulaeors for chassis mounting.

United Insulator Co., Ltd.,
12/22 Laystall Street, London, E.C.1.

Loudspeakers

5 in. to 10 in. permanent magnet types. The energised magnet models are at the moment confined to radio manufacturers and to fill export requirements.

British Rola, Ltd.,
Georgian House, Bury Street, St. James's, London, S.W.1.

Magnets

Mullard "Ticonal" magnets are manufactured by a special method which results in close laboratory control over alloy and processing and the application of the magnetic field during this treatment. This processing in a magnetic field produces directional properties in the finished magnet, *i.e.*, the magnetic properties in the predetermined direction are considerably greater than in any other direction. The finished magnet can be magnetised in either direction along the magnetic axis.

Mullard Wireless Service Co., Ltd.,
Century House, Shaftesbury Avenue, London, W.C.2.

Potentiometers

The type P.I.W. is capable of 15-20 watts dissipation (linear type, uniformly loaded), and it is the only potentiometer wound to values as high as 500,000 ohm. It can also be arranged to have continuous rotation of the contact arm. In the smaller sizes, tapered, graded, logarithmic, semi-logarithmic or inverse windings up to 50,000 ohms maximum can be supplied, or resistances can be wound to customers' own specification. Non-inductive windings are supplied up to 10,000 ohms maximum.

Reliance Manufacturing Co. (Southwark), Ltd.,
Sutherland Road, Higham Hill, Walthamstow, E.17.

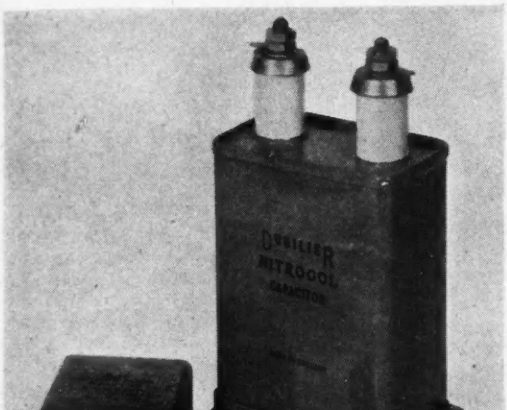
Toroidal potentiometers wound to a high degree of accuracy on bakelite formers. By means of special contacts inserted in the moulding, connexion may be made with the winding at a number of points. Silver contact rings enable the wiper arm to rotate continuously. Standard resistance of the type 360/4/2 is 30,000 ohms with a linear accuracy better than 0.1 per cent.

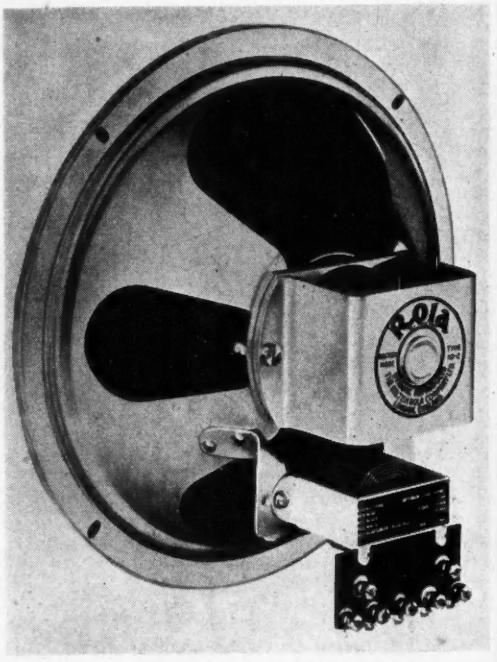
P. X. Fox, Ltd.,
Hawksworth Road, Horsforth, Yorks.

Resistance Unit

This unit consists of 11 manganin resistors, each provided with its own pair of blade contacts, bifilar wound

EXHIBITIONS





Selection of Dubilier condensers of new and improved types. (Right) 10-in. moving coil speaker by British Rola, Ltd.

upon formers and secured between two stout end cheeks. The end cheeks are fitted with two large diameter bearings and provided with a square operating spindle which passes through the instrument panel, and upon which the control knob is fastened. As each resistance is electrically isolated from all others and the frame and passes into the same position during measurement, the circuit condition is constant. Individual resistances can be wound to any value up to 20,000 ohms.

Labgear, Willow Place, Cambridge.

Seals, Hermetic

Hermetically sealed-in cans using U.I.C. hermetic seals which stand up to pressure of more than 30 lb. per square inch.

United Insulator Co., Ltd., 12/22 Laystall Street, London, E.C.1.

Glass-to-metal seals for transformers and condensers.

Belling and Lee, Ltd., Cambridge Arterial Road, Enfield, Middx.

Switch Key, Low Capacitance

Designed for multiple switching in conditions where very low capacitance between springs and frame is necessary. Maximum capacitance between any spring and frame is 3 $\mu\mu$F, and between any two adjacent springs it is 2 $\mu\mu$F.

Telephone Manufacturing Co., Ltd., Martell Road, East Dulwich, S.E.21.

Switches

Type MHC oak switches are designed to give the highest degree of insulation with low radio-frequency loss; low-loss ceramic material being used for both stators and rotors. Contacts are normally of the "shorting" type, which maintains connexion with one contact until after the next is made. "Non-shorting" types can, however, be supplied to order. Each switch is supplied complete with fixing nut and locking washer, but without knob.

British N.S.F. Company, Ltd., Keighley, Yorks.

Switch, Rotary Ceramic

A two-wafer ceramic switch with a normal working voltage of 0.1,000 volts and capacitance, between contacts, of less than 0.1 pF. The insulation resistance between contacts is 16,000 megohms after a K.110 test, the contact resistance is 0.002 ohm and the power factor of the insulator 0.0005 at 10 megacycles. The switch is fitted with silver alloy contacts and up to 6 wafers can be fitted with a single operating mechanism.

Wright and Weaire, Ltd., High Road, Tottenham, N.17.

Telephone Equipment (Sound Powered)

This telephone equipment generates within the transmitting and receiving units all the power required for transmitting speech over considerable distances. No batteries are required.

Telephone Manufacturing Co., Ltd., Martell Road, East Dulwich, London, S.E.21.

Thermostats

Dimensions of the type T.10 are 48 mm. × 16 mm. × 10 mm., and the temperature range 50° F. to 300° F. (10° C. to 150° C.). The current-carrying capacity is 0.3 amp., A.C./D.C. The unit is housed in a ceramic case.

Electrothermal Engineering, Ltd., 270 Neville Road, London, E.7.

Transformers

The type "101" is a multi-purpose transformer providing ratios to suit almost every output valve (12 to 1;

EXHIBITIONS

18 to 1; 24 to 1; 30 to 1; 36 to 1; 48 to 1; 60 to 1; 72 to 1). Three ratios centre-tapped for push-pull.

Goodmans Industries, Ltd., Lancelot Road, Wembley, Middlesex.

Woden H.T. transformers without filament windings (650-0-650 volt and over) have a 5 volt at 0.5 amp. winding incorporated. This may be used in conjunction with an indicator lamp to give warning when H.T. is switched on.

Woden Transformer Co., Ltd., Moxley Road, Bilston, Staffs.

Small intervalve coupling transformers intended for hearing-aid, ultra-small portable and "walkie-talkie"-type equipment.

A. F. Bulgin and Co., Ltd., Bye Pass Road, Barking, Essex.

A sectionalised audio-frequency transformer of the midget-screen type (*see* page 124), consisting of two balanced binocular-wound coils, assembled on to a mumetal core in such a way that voltages induced by the primary will be in series while the voltages induced by the external field will be in opposite phase and cancel. A copper electrostatic screen is incorporated into the coil structure to prevent the passage of stray capacitive and static currents from primary to secondary and to provide a balance to earth. All models have a uniform frequency response within 1.5 db. from 50-15,000 c/s.

Parmeko, Ltd., Percy Road, Aylestone Park, Leicester.

5 VA to 5 kVA power transformers, double or auto wound. Manufactured in the following assemblies: normally air-cooled open construction; shrouded types; in steel cans, bitumen loaded; oil or petroleum-jelly filled.

Associated Electronic Engineers, Ltd., Stanmore, Middlesex.

Valve Retainers

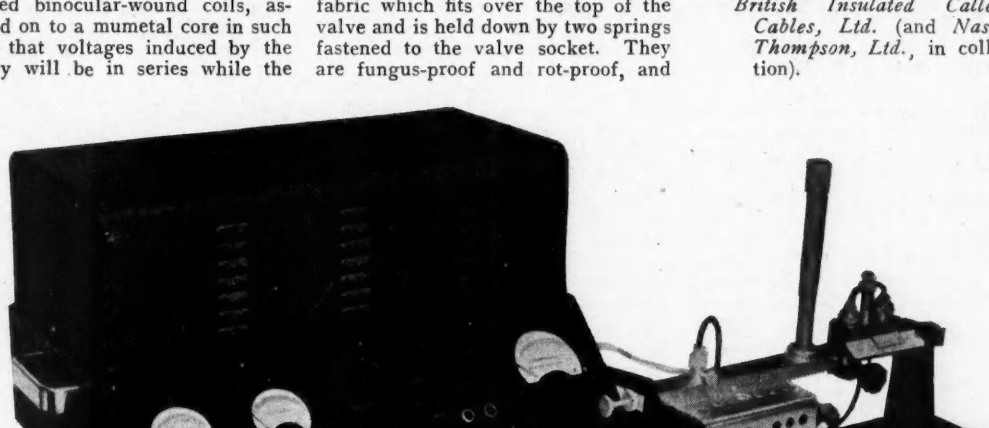
These valve retainers are in the form of a closely woven net of glass fabric which fits over the top of the valve and is held down by two springs fastened to the valve socket. They are fungus-proof and rot-proof, and are supplied in ten sizes which cover all types of medium valves.

Electrothermal Engineering, Ltd., 270 Neville Road, London, E.7.

Waveguide Test Bench

The type 1 10,000-megacycle (3 cm.) waveguide test bench is designed to enable the characteristic properties of specific waveguide systems to be measured and the principles of 3 cm. waveguide propagation to be demonstrated. Although primarily intended for use with rectangular waveguides (the internal dimensions of which are 1 in. × ½ in.), adapters are provided for testing rectangular guides 1 in. × 11/32 in. or circular guides 1⅛ in. or ⅞ in. diameter. The scope of the equipment for demonstration purposes is considerably increased by the several accessories which are provided as separate items. The waveband covered by the test gear is 3.14 centimetres to 3.26 centimetres.

British Insulated Callender's Cables, Ltd. (and *Nash and Thompson, Ltd.*, in collaboration).



Waveguide test bench described in column 3.

3. North-East Coast Exhibition

THE North-East Coast Exhibition of Scientific and Engineering Inspection Equipment was opened by Sir Charles G. Darwin, K.B.E., M.C., M.A., D.Sc., F.R.S., Director of the National Physical Laboratory, in Newcastle-on-Tyne on February 12.

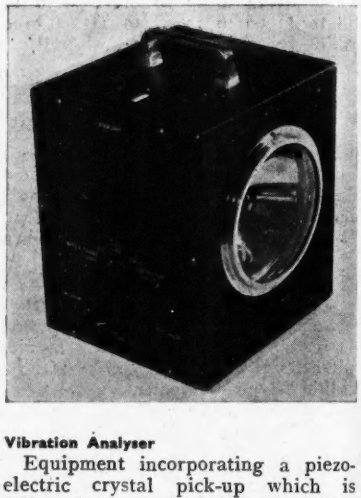
In his opening speech, Sir Charles Darwin said there is perhaps nothing very new in the idea that things ought to be tested during each process of manufacture; what is newer is the appreciation of the time and expense saved by adopting quite elaborate methods of control, starting from the chemistry and the temperature of the smelting furnace, through the metallurgical constitution of the ingot, the strength and hardness of the blank, right up to the dimensions of the finished article.

A significant feature of the apparatus exhibited was the variety

EXHIBITIONS

(Left) Vibration analyser—*Salford Electrical Instruments, Ltd.*

(Right) Stroboflash—*Dawe Instruments, Ltd.*



of methods used in it. Principles of hydraulics, optics, electricity, magnetism and electronics were adopted, as well as the more commonplace but still immensely useful processes of straight measurement and gauging. Sir Charles remarked that two instruments based on radically different ideas often do the same job. He mentioned a problem which his own laboratory had been called upon to solve in the matter of checking that every machine gun cartridge should have the requisite two holes in it to carry the flash from percussion-cap to charge. Previously the method used was to blow air through the holes, but this was not entirely satisfactory, and the problem was solved by shining light through the holes onto a photo-electric cell.

In conclusion Sir Charles said that his personal opinion was that the tendency to-day is rather away from the go and not-go type of gauge into the measuring instrument; this is because we have in the manufacture of so many products developed the methods of statistics and have learnt that for a great many articles an inspection of five or ten per cent. will give one better and much cheaper control of the process of manufacture than can be got even by a hundred per cent. inspection using older methods.

Much of the electronic equipment shown had already been exhibited at the Physical Society's Exhibition in January, and was reviewed in the February and March issues of this journal; the following items, however, are additional to those reviews.

Stroboflash

A mains-operated portable instrument which enables a moving object to be illuminated intermittently, and thus produce the effect of slowing down or stopping motion over the range 600-14,000 r.p.m., for determining and checking the speed of rotation on revolving machinery and for studying the amplitude and direction of vibration in oscillating and reciprocating mechanisms.

Accessory units are the Stroboflood which provides greater light output for photographic purposes or for floodlighting a large area, and the Strobotorch, a unit for working at difficult angles.

Dawe Instruments, Ltd., Harlequin Avenue, Gt. West Road, Brentford, Middlesex.

Thickness Meter

A new instrument designed to measure thickness of all types of non-magnetic plating, paint, insulating films, etc., when applied to ferrous metals. A special feature is the use of a single point contact which permits readings to be taken on other than flat surfaces.

Chronoscope

This equipment measures time intervals of one millisecond and upwards in a scale-of-two progression. Among other things it measures the time interval between pulses generated by the passage of a projectile over a pair of photo-cells spaced a known distance apart.

Marconi Instruments, Ltd., St. Albans, Herts.

Vibration Analyser

Equipment incorporating a piezo-electric crystal pick-up which is followed by a high-gain amplifier with a frequency range of from 0.2 c/s. to 20,000 c/s., the vibrations being shown on a microammeter. Typical measurements of which it is capable relate to vibrations due to bench shafts, piston scrape and roller bearing imperfections.

" Miniscope " Miniature Oscilloscope

Claimed to be the smallest complete oscilloscope in the world, this instrument weighs about 6 lb., and can be operated from either A.C. mains or a 6-V accumulator. (See *Electronic Engineering*, Feb., 1945.)

High Voltage Diode Valve Voltmeter

A valve voltmeter capable of reading up to 10,000 volts over a frequency range of 50 cycles to 100 megacycles. It is built into a neat wooden case and is A.C. mains operated.

Salford Electrical Instruments, Ltd., Silk Street, Salford 3.

F. G. KEATES,
GATESHEAD.

Books reviewed in this Journal can be obtained from

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BOOK REVIEW

Electron Optics and the Electron Microscope

V. K. Zworykin, G. A. Morton, E. G. Ramberg, J. Hillier and A. W. Vance. (New York : John Wiley & Sons Inc.; London : Chapman & Hall Ltd., 1945, $10.) xi + 755 pp.

This book, written by the brilliant R.C.A. team responsible for the development of the most successful of all commercial electron microscopes, fulfils an urgent need. It is the first comprehensive textbook on electron microscopy in English, and at the same time the most complete exposition of electron lens optics in any language.

Of the first part (337 pages), two chapters contain a general introduction to electron optics and its various practical applications, the rest is devoted to a description of the principles, design, operation and achievements of the electron microscope. This part can be read with profit not only by electrical engineers who are no electronic specialists, but also by chemists, biologists and by the scientifically interested general public who want extensive first-hand information on the most important instrumental development of the last decade. The second part (398 pages) is a thorough mathematical treatise on electron lens systems, which will be invaluable to all specialists in theoretical electron optics. Thus the two parts of the book will appeal to very different numbers of readers. In view of the rather high price of the book many non-specialists would probably welcome a separate edition of the first part.

Though the preface is dated August, 1945, it appears that very little material was included after the end of 1944, or even after spring, 1944. No mention is made of the "Universal" and "Console" types of R.C.A. electron microscope, which were announced in that year. But almost all important earlier developments and publications have found their place in the book. Though the description of the R.C.A. instruments and of their achievements naturally occupy most of the space, other, especially German, developments are very adequately discussed. Particular thanks are due to the authors for summing up a vast amount of information, derived from German sources which are not easily accessible in this country.

The presentation is very clear and logical, with hardly any repetitions or noticeable omissions, which is not often the case in works of joint authorship. The skill with which the vast theoretical material in the second part is ordered and contributions of different authors are welded into a whole deserves special notice. Only the specialist can appreciate the brilliancy of Chapter 16, in which the formidable general theory of lens aberrations is built up from papers by Rogowski, Glaser and Scherzer in a way which is likely to serve as a model for all future books on this subject. The specialist will also notice many original contributions to the theory, and will perhaps regret that the joint authorship does not make it possible to give the individual authors the credit which they deserve.

This is not the place for a discussion of the few points in which the views of the authors and of the reviewer are at variance. Chief among these is the small importance which the authors attribute to inelastic electron collisions in the image formation of thin objects. It appears that at the time of writing they had not taken adequate notice of the important experimental results of Ruthemann. Consequently, they insist on the interpretation of certain contour effects as Fresnel diffraction fringes, while the reviewer considers them a sort of "chromatic fringes" and as evidence of energy losses by discrete amounts.

It is a matter for regret that a presentation can be seldom at once logical and historical. The authors have chosen the logical way, hence those who approach the subject for the first time through this work can hardly expect to get a fair idea of the historical origin of electron optics. The name of H. Busch is mentioned only once, on page 493. It may be somewhat difficult for the reader to guess from this one passage that Busch initiated the whole new science by putting on paper for the first time the magic word combination "electron lens."

The authors have succeeded in producing a book which will be of great interest to the general scientific public, and indispensable for the specialist.

D. GABOR.

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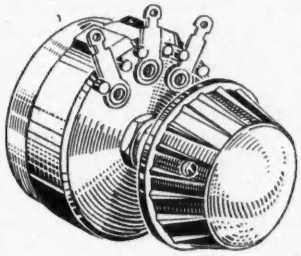

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ABSTRACTS OF ELECTRONIC LITERATURE

INDUSTRY

Silicone Resins for Electrical Insulation
(G. L. Moses)

The properties of silicone resins are significant where thermal aging or excessive moisture governs the application. They may be used to bond and treat mica, asbestos and fibrous glass to produce composite insulations with superior thermal aging properties. The use of silicones in this combination improves the thermal stability of the insulation to the point that temperature aging need no longer be a basic limit in machine design. Potentialities of application are those cases where requirements such as lower weight, higher temperature, longer life and better moisture resistance are necessary.

—*Elect. Wld.*, 24/11/45, p. 79.*

Electric Eye Tracing in Machine Cutting
(W. Bergerow)

Tracing with electronic equipment is claimed to be accurate to within a very few thousandths of an inch. The features of electronically controlled steel cutting are: flexibility, accuracy, economy and quality for superior to conventional methods of guiding cutting torches. Intricate shapes or contours impossible to cut with other types of tracing devices, may be cut closely to dimensions with this fully automatic equipment. Rapid manual movement from point to point to facilitate lining up and drawing in relation to the material to be cut is assured through control switches. Low cost and ease of drawing or silhouette preparation make possible complex design reproductions while reducing greater fatigue, and the chain cutting technique opens new avenues to increased production.

—*Weld Jour.*, October, 1945, p. 941.*

The Design and Use of Radio-Frequency Open-Wire Transmission Lines and Switchgear for Broadcasting Systems
(F. C. McLean and F. D. Bolt)

The paper describes the various types of transmission lines in use at transmitting stations of the British Broadcasting Corporation, their impedance, attenuation and power-carrying characteristics, together with results of various tests, general details of construction, and methods of matching the load to the transmission line. The major part of the work described was carried out before the end of 1943.

The paper is written primarily from the point of view of the engineer engaged on design and practical work in the field. Data are included enabling the most suitable transmission line for any practical purpose to be designed. The range of frequencies considered is from 0.2 to 25 Mc/s.; of this range those up to 2 Mc/s. are considered as medium waves and those from 2 Mc/s. to 25 Mc/s. as short waves.

—*Jour. I.E.E.* (to be published).

Frequency-Modulated Magnetic-Tape Transient Recorder
(H. B. Shaper)

A transient recorder having a frequency range of 0.02 to 1,000 c/s. with useful response up to 2,000 c/s. is discussed. The transient is recorded on a loop of magnetic tape driven by a synchronous motor and is played back every 0.1 sec., on an oscilloscope screen. Thus a steady image of the transient is obtained. Excellent signal-to-noise ratio (40 decibels) is obtained by the use of a 10 kilocycle, frequency modulated carrier. Each recording can be obliterated by simply pressing a button with no material being consumed.

—*Proc. I.R.E.*, November, 1945, p. 755.

THEORY

Dynamics of Electron Beams
(D. Gabor)

This paper presents the Hamilton canonical equations and the Hamilton-Jacobi equation in forms in which they are useful to the electronic research worker. The types of electron flow considered are the motion of a single electron, regular electron flow and electron flow with random motion. Each of these is discussed under three subdivisions, namely: motion in electrostatic fields, in static electromagnetic fields and in variable electromagnetic fields.

—*Proc. I.R.E.*, November, 1945, p. 792.

MEASUREMENT

The Design of X-Ray Powder Cameras
(M. J. Buerger)

This paper presents constructive criticisms of current powder camera design, and describes briefly a series of instruments having desirable features. Among the issues discussed are adjustments, recovery of adjustments, desirable diameters, important recording ranges, film arrangements, fitting the film to cylindrical form, design of direct beam systems, elimination of air-scatter, specimen attachment and adjustment, and scanning. The following special instruments are also discussed: high temperature cameras, large spacing cameras, and film cutters and punches.

—*Jour. App. Phys.*, Sept., 1945, p. 501.*

Electronic Wattmeter
(L. R. Malling)

This article discusses the limitations of the conventional A.C. wattmeter and shows how present-day circuit techniques and modern vacuum tubes may be applied to construction which will overcome the difficulties of the early design and make the vacuum-tube wattmeter a permanent and useful tool of the electronic engineer. A cathode follower is substituted for a transformer and a push-pull parabolic rectifier used to provide a sensitive, wide-range electronic wattmeter that is useful up to higher frequencies and loads the circuit less than electrodynamic types.

—*Electronics*, November, 1945, p. 133.

A Feed-back Amplifier for Ionisation Currents
(F. T. Farmer)

A direct reading X-ray intensity meter comprising a small thimble chamber on the end of a flexible cable, and measuring dose rates of 1 to 50 r. per min. with a rapid response is described. A large degree of negative feed-back is used to stabilise against changes in valves and supply voltages, and gives a precision measuring device with a linear response to radiation intensity. Circuit details are given, and it is explained how, by simple switching, the instrument may be used to measure also small doses of X-rays, such as occur in diagnostic work.

—*Brit. J. Radiol*, January, 1946, p. 27.*

* Abstracts supplied by the courtesy of Metropolitan Vickers Electrical Co. Ltd., Trafford Park, Manchester

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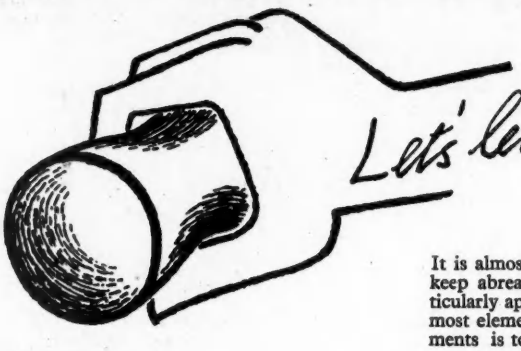

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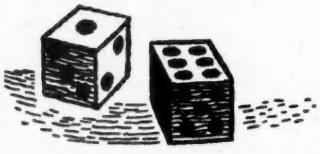

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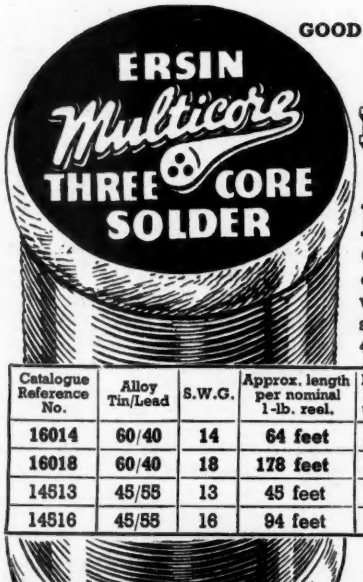

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APRIL MEETINGS

*NOTE.—In general, visitors are admitted to the meetings of scientific bodies on the invitation of a member, or on application in writing to the Organising Secretary at the address given. In certain cases (marked *) tickets may also be obtained on application to the Editorial offices of this Journal.*

Institution of Electrical Engineers

All meetings of the London Section will be held at The Institution of Electrical Engineers, Savoy Place, Victoria Embankment, London, W.C.2.

Ordinary Meeting

Date: April 25. Time: 5.30 p.m.
Lecture:
The Thirty-Seventh Kelvin Lecture "Nuclear Physics and the Future."
By:
Professor M. L. Oliphant, F.R.S.

Radio Section

Date: April 16. Time: 5.30 p.m.
Lecture:
Discussion on "Interference Problems Arising from Industrial Electronic and Electromedical Apparatus."
By:
M. R. Gavin.

The Secretary:
The Institution of Electrical Engineers, Savoy Place, Victoria Embankment, London, W.C.2.

Cambridge Radio Group

Date: April 29. Time: 6 p.m.
Held at:
Cambridge Technical College.
Lecture:
"The Suppression of Impulsive Interference in Amplitude Modulation Receivers."
By: D. Weighton, M.A.
Group Secretary:
D. H. Hughes, c/o Pye Ltd., Radio Works, Cambridge.

The Television Society *

Date: April 3. Time: 6.30 p.m.
Held at: The Royal Institution, Albemarle Street, W.1.
Lecture: "Ambrose Fleming: His Life and Early Researches."
By: Dr. J. T. MacGregor Morris, M.I.E.E.

Note: The first of a series of annual lectures commemorating the work of Sir John Ambrose Fleming.

Lecture Secretary: G. Parr, 68 Compton Road, N.21.

Institute of Physics

Electronics Group

Date: April 9. Time: 5.30 p.m.
Held at:
Royal Society, Burlington House, Piccadilly, W.1.
Lecture:
"Velocity Modulation Tubes."
By:
Dr. J. H. Fremlin (Birmingham University).
Group Secretary:
A. J. Maddock, M.Sc., F.Inst.P., Messrs. Standard Telephones and Cables, Ltd., Oakleigh Road, London, N.11.

Manchester and District Branch

Date: April 26. Time: 7.0 p.m.
Held at:
Large Physics Theatre, Manchester University.
Lecture:
"Dielectric Heating."
By:
A. J. Maddock, M.Sc., F.Inst.P.
Hon. Secretary:
Dr. F. A. Vick, O.B.E., F.Inst.P., The University, Manchester, 13.

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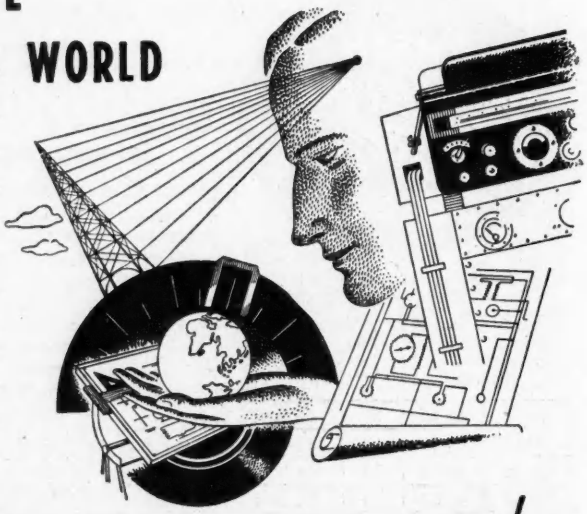

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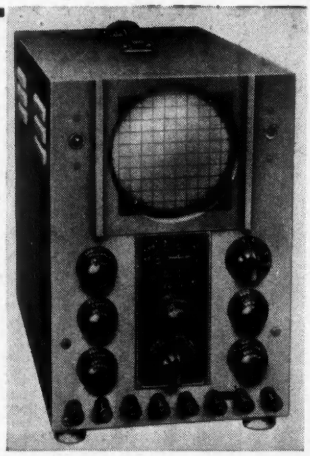

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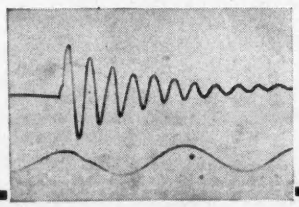

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This change is instituted in the interests of optimum production and the well-being of our staff, and consequently, we trust, in an improved service to the ultimate benefit of our customers.

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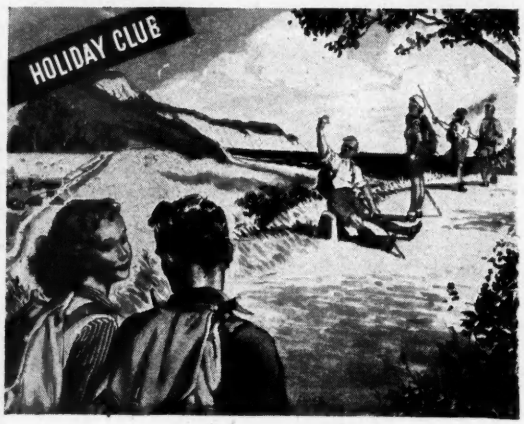

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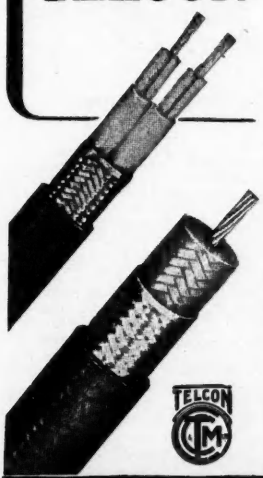

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Vacancies advertised in these columns do not relate to men between the ages of 18 and 50 inclusive, or women between the ages of 18 and 40 inclusive, unless they are exempted from the provisions of the Control of Engagements Order, 1945, or the vacancies are for employment excepted from the provisions of that order.

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1946 DE WITT 30-watt amplifier chassis with all valves, heavily built on 12 in. by 8 in. by 3 in. grey cellulose chassis, two outputs, 15 and 2.5 ohms, superb reproduction with the new De Witt HiFidelity Bass and Treble Uplift circuit for A.C. mains, 10 gns. complete. See below.
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3-GANG tuning condensers with 2-speed SM drive and pointer, 8/6 ea.; 2-gange with trimmers, 7/3; 4-valve TRF chassis, 5/- ea.; 5-valve ditto, with mains transformer cut-out, 12 in. by 8 in. by 3 in., cadmium plated, 9/6. **CONDENSERS.** 8 mfd. 450 vw., 2/3; 25 vw., 1/3; .5 mfd., 1/-; .3 mfd., 10d.; .1 mfd., 6d.; .0005 mfd., 5d.; trimmers, 5d. ea. Volume controls, .5 meg., less switch, 2/6 ea. Twin tag strips, 3d. ea. Twin socket strips, A. and E., Gram, or plain, 5d. ea. Coloured plastic 2 mm. sleeving, red, blue or green, 2d. yd.; below.
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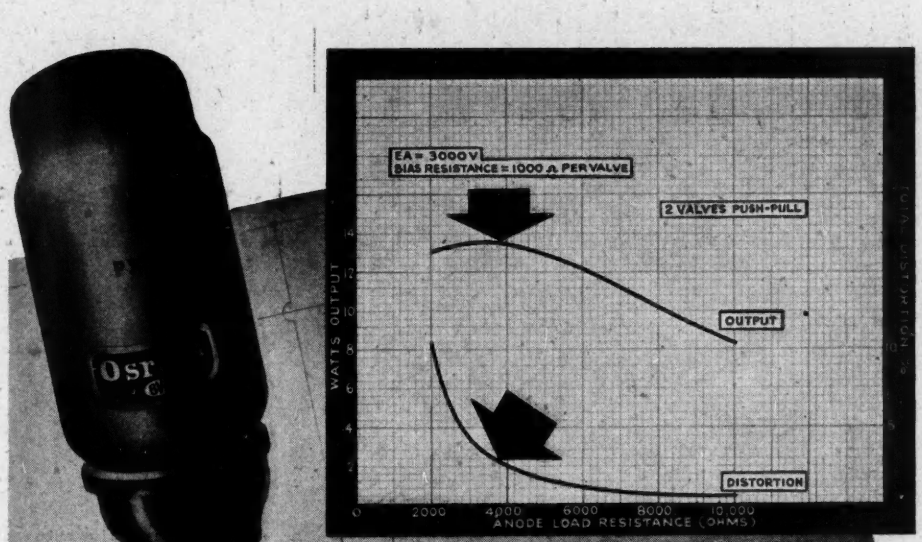

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12 Hy. 60 mA	14 10	20 Hy. 60 mA	18 0
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Shielded to reduce magnetic flux, in black finished case.

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Designed to minimise losses on H.F. Eddystone and Denco coils are recognised pre-eminent in their respective applications.

EDDYSTONE famous 6-Pin Coils now available again.

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DENCO horizontal mounting plug-in polystyrene coils.

Range	Approx. Coverage in Mc/s			Tuned	
1	1	—	2	100 pF	Each range available in 4 types:—
2	2	—	4.5	100 pF	"Blue" Grid and aerial windings (4-pin) ... 3/6
3	4	—	9	100 pF	
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6	30	—	60	50 pF	"Green" Grid, reaction and Primary (6-pin) ... 4/6
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